DESIGNING A DRAGONFLY TRAIL IN THE NATIONAL BOTANICAL GARDENS PIETERMARITZBURG

By

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ABSTRACT

Dragonfly assemblages and their biotope preferences in the National Botanical Gardens, Pietermaritzburg, South Africa were investigated. The information served as background for increasing public awareness and education by designing a dragonfly observation trail. Multivariate analyses of data, classified 20 a priori selected sampling units into four ecologically meaningful biotope types, each with characteristic dragonfly assemblages. These biotopes were: 'waterfall', 'forested river', 'shaded pond/stream' and 'open ponds/dam'. Species-environmental variables correlations were significantly high for six out of twelve, measured environmental variables: pH, percentage shade, vegetation (structural and compositional), ambient temperatures, water temperatures, and water depth. Sunlit ponds/dam had higher species richness and diversity than the other water bodies. The months of November to April were significantly high in species richness and diversity, and were characterized by both rare and abundant, and both localized and widespread species. The winter months (May to October), in contrast, were characterized by only the widespread and abundant species. Questionnaire responses were used to test the popularity of the concept of a dragonfly trail, and showed a high level of awareness and commitment on the part of respondents (visitors to the botanical gardens) across all age groups. There was a strong response to knowing more about dragonflies (using a trail) and to become involved in conserving them. The scientific results, the responses to the questionnaire, and practical feasibility, all indicated that the instigation of a trail was possible. After some preliminary trials, a full trail was designed, which is now being installed by the National Botanical Gardens for the benefit of a wide sector of the public and for heightening public awareness of the need for dragonfly and other invertebrate conservation. This study was partly in response to the IUCN Status Survey and Conservation Action Plan: Dragonflies, and to widen the value and appeal of the botanical gardens, which are an already well-established public asset.

PREFACE

The field work described in this thesis was carried out in the National Botanical Gardens, Pietermaritzburg, South Africa. The analysis was carried out in the school of Botany and Zoology, University of Natal, Pietermaritzburg. The study was conducted from May 1998 to November 1999, under the supervision of Professor Michael J. Samways.

This study represents original work by the author and has not been submitted in any form to another university. Where use was made of the work of others, it has been duly acknowledged in the text.

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CHAPTER 1

INTRODUCTION

1.1 Insect conservation

Worldwide, there are large-scale landscape changes taking place that are altering habitats and changing landscape geometry. These impacts are changing species assemblages and ecosystem functioning (Soulé 1989), which in turn is affecting the provision of ecosystem goods and services necessary for human survival (Wardle 1999). Among the landscapes being modified is the savanna and its fauna (Scholtz and Chown 1993). As a result, species losses affect the provision of ecosystem goods and services necessary for human survival (Wardle 1999).

Conservation strategies adopted for most vertebrates cannot be applied to the great majority of invertebrates. Invertebrate home ranges are generally smaller (Ehrlich 1992), and their populations often exist at much higher numbers, and often fluctuate to such an extent that local populations are occasionally extirpated (Dempster 1989). Microhabitats are important to insects which are often dependent on particular species of plants and sets of small-scale environmental conditions, both for the adult and their larvae (Corbet 1993 ; Drewett 1988; Moore 1991a). Perhaps the most significant difference between vertebrates and invertebrates is that most invertebrate species have not yet been described. About 950000 insect species have been described with the total estimate being between 10 and 15 million (Groombridge 1992). Insufficient time and lack of expertise have, in turn, limited the ecological understanding of most of these species. Therefore, conservation biologists are called upon to devise rapid and yet effective techniques for evaluating entire ecosystems, which involves planning, strategizing and monitoring of results (Ehrlich 1992).

Insects show great morphological, behavioural and physiological variations, resulting in their being a major component of terrestrial and freshwater ecosystems. Insects as life forms, are often characterized by polymorphisms, especially developmental polymorphism, where the larva is fundamentally and ecologically a different animal from the adult.

The success of insects (May 1989; Gaston 1992; Groombridge 1992) is partly related to their size. They are small enough to exploit many of the nooks and crevices and tissues making up the complex geometry of landscapes and their components (Mandelbrot 1983). However, for most of the named, and all of the unnamed species, there is no knowledge of their biology. This great dearth of information means that any really meaningful conservation as a whole, must consider them as a group, rather than one species at a time. Pivotal to insect conservation are the many roles that they play in many aspects of ecosystem functioning, such as nutrient cycling, influence on soil structure, pollination, predation and parasitism. Also, energy flow through some insect populations can be very high (Odum *et al.* 1962), while the dominant biotic interaction on earth is between insects and plants (Strong *et al.* 1984). Although plant diversity is an enabling phenomenon for insect diversity, it is not necessarily the sole generator. Local and regional insect species richness is also attributable to the complexity of plant architecture and the absence of excessively harsh environmental conditions e.g severe drought, fierce fires and very cold winters (Samways 1993).

It is important to recognize that insects are the subjects exemplifying the biodiversity of an area and they are the monitoring tools for measuring changes in biodiversity. Naturally, there are some interrelationships. For example, insect populations that monitor changes are in themselves changing. Conversely, autecological insect conservation projects involve regular monitoring of the subject population. Nevertheless as subjects, insects can be conserved as an integral part of landscape preservation (Samways 1993).

Some insects are valuable as flagships in conservation biology and for making insect conservation management decisions (Samways 1989). Insects have value in determining the extent to which a landscape is fragmented or variegated (Ingham and Samways 1996). They occur at relatively high population densities and are often conspicuous. With these characteristics, they reflect suitability of conditions for a variety of other non-insect species. Flagship insect species may be conservation subjects or indicators for the protection of other species especially in the same genus, family or order. Furthermore, insects and other invertebrates have often been used as monitors, indicators and elements for the compilation of index values for the quality of certain ecosystems (Disney 1986).

Monitoring of water quality of streams for example, has generally used particular taxa e.g. Plecoptera, Ephemeroptera, Odonata or aquatic Coleoptera (Spellerberg 1991). Different assemblages however, have different merits. Often it is the range of sensitivity among the different species that may be of utmost importance rather than simple extreme sensitivity to very low levels of pollution. In most terrestrial and fresh water ecosystems, the insect indicators are also the subjects, with entire community conservation often being the management goal.

1.2 Current status of insect conservation in southern Africa

Although substantial areas of southern African savanna already have formal protection, insect conservation is still much in need of development. Insects and their habitats are threatened in savanna areas by increasing human population, social conflicts and poor agricultural practices (Scholtz and Chown 1993). To date, the meager attention to insect conservation in the southern Africa has been based essentially on crisis management of species perceived to be threatened (Henning and Henning 1989). This single-species approach may be of value in protecting a particular species and its habitat, but is of little value in protecting the diverse plant assemblages and their related insect faunas. Safe-guarding a wide range of habitats is vital, even though it is unlikely that they will be managed specifically to conserve insects (Samways 1989b).

A critical problem facing insect conservation biology in southern Africa is the lack of taxonomic knowledge and the lack of trained personnel to obtain that knowledge. Between 5% and 50% of southern African insects are estimated to have been described, although the level of knowledge is very uneven among the various taxa (Scholtz 1990). Conservation programmes can only be as good as the systematic research on which they are based (Erwin 1991). Although a large number of southern African taxa, including many savanna species, have been systematically revised and are reasonably well-known, the status of component species (even those with restricted distributions or those that are thought to be rare) remain unknown. This is largely due to the fact that very high financial cost is associated with the compilation of a biological inventory (Lindenmayer *et al.* 1991).

In as much as accurate estimates cannot be made without reliable inventories, it is most likely that there are many less visible and more critically-threatened species that are in need of urgent attention. Habitat degradation and destruction are likely to necessitate constant revision of their numbers (Groombridge 1992).

Unlike other biomes, relatively little attention has been given to insect conservation at the habitat or landscape level in the savanna (Scholtz and Chown 1993).

1.3 The Odonata in conservation

1.3.1 As subjects/tools

The Convention on Biological Diversity was signed at the Earth Summit at Rio de Janeiro in June 1992. Dragonflies are part of the world's biodiversity and therefore must be conserved. Dragonflies have also proved to be useful monitors of anthropogenic disturbances to river systems (Watson *et al.* 1982; Carchini and Rota 1985; Stewart and Samways 1993; Clark and Samways 1996). Additionally, their localized distribution pattern has been related to landscape changes, with dragonflies being both the subjects and the monitoring tools (Samways 1989a; Omerod *et al.* 1990; McGeoch and Samways 1991). A major world-wide conservation strategy for dragonflies has been developed by the World Conservation Union (IUCN) Species Survival Commission (SCC) Odonata Specialist Group (Moore 1982). This has involved the production of an Action Plan (Moore 1997). There have also been regional surveys assessing conservation status and proposing protective measures (Watson 1982a; Van Tol and Verdonk 1988; Samways 1993).

Brown (1991) bases the selection of insects/invertebrate indicator groups on a range of desirable qualities. The Odonata ranks in suitability among the top 20% in this selection. As indicators, they are valuable; taxonomically and ecologically for the following reasons: i) they are highly diversified, ii) many of them have specific and easily recognizable ecological preferences, iii) they are taxonomically well known and easily identified. iv) they are abundant and easy to find in the field, v) they are relatively sedentary through territoriality, and vi) their response to disturbance is highly predictable, rapid, sensitive and can be analyzed.

A convenient working scheme for the evaluation of an inventory of Odonata species of a habitat is given by Schmidt (1985).

The importance of focusing on the last-stage larva, exuviae or adults is that it means they have successfully completed larval development within a particular biotope. Observation of reproduction/breeding behavior provides valuable supplementary information (Corbet 1993, 1999). Larval Odonata, on the other hand, are cryptic, inconspicuous and difficult to identify, making the larval stages often impractical as conservation- monitoring tools, especially in Africa. Nevertheless, Hawking and New (1999) have shown that adults are good surrogates for the larvae. Yet the use of adults alone, especially as indicators, must be done with caution, as the occurrence of an adult and observed oviposition at a water body does not always imply successful breeding and larval survival at that particular water body. For example, *Pantala flavescens* (Fabricius) can often be observed ovipositing in artificial ponds but with little chance of breeding success (Samways and Caldwell 1989). Odonata are particularly well suited to monitor landscape physiognomy and quality assessment of freshwater. They are also valuable in decision making for conservation for endemism on the one hand, and typicalness on the other. Ideally however, their use should be in congruence studies, where other biotic groups are employed alongside them (Samways 1993).

1.3.2 Threats to dragonflies

Wetlands (potential dragonfly habitats) are one of the most threatened of wildlife habitats. Also, with intensification of agriculture, many stenotopic species are under severe threat. Species losses are incurred mainly as a result of pollutants, high water requirements for crop production and the conversion of riverine wetland vegetation into crop-land as well as into built-up areas (Moore 1991a; Corbet 1999). The clearing of tropical rainforests in particular, impose the greatest threat to dragonflies (Moore 1997). Furthermore, drainage and excessive water extraction destroy many freshwater habitats, while lowering the water table can turn permanent water bodies into temporal ones, and as a result, they cannot support dragonflies with a long developmental period. In some streams and ditches, changes in the flow-rate can cause local loss of species. In KwaZulu-Natal, the greatest threat is the conversion of wetlands for agricultural purposes (Begg 1986).

In view of the above, action to conserve dragonflies is urgent through a wide range of measures.

In Britain, about 11 out of the original 38 breeding species were under threat or existed precariously (Moore, 1976). The British government spent only a small fraction of the money allocated for agricultural development on nature conservation. Nevertheless, much progress has been made. All dragonfly species, for example, are protected in Germany (Von Eislöffel *et al.* 1992), while in Japan, dragonfly reserves are being established. At such reserves, the public enjoys 'dragonfly watching' and makes species lists (Moore 1987), and in the process, becomes much more aware of these insects.

Corbet 1999 has discussed action needed to protect dragonflies and their habitats in the short to medium term, addressing first the motivation for such action and the main tasks involved in implementing it has been discussed.

1.3.3 Aspects of dragonfly biology relevant to their suitability as indicators

An important aspect of Odonata biology is the distinctive range of species biotope preferences (Steytler and Samways 1995; Corbet 1999). The vegetational conditions of water and nature of the substrate, determine the local and regional distribution of Odonata larvae (Pinhey 1978). Localized species are restricted by adult preferences as well as those of the larvae. The adults being the dispersal and reproductive stage, must select suitable breeding/oviposition sites that are structurally and ecologically preferred to ensure the completion of larval development. For example, most Zygoptera and Aeshnidae, insert their ovipositors into often submerged plant tissues to lay their eggs (endophytically) (Corbet 1962). The entire adult life centres around reproduction (Corbet *et al.* 1960, 1999). Between the aquatic and aerial stages in Odonata life history, there are two transitional events: emergence and oviposition. Whereas a population scatters after emergence, it aggregates before oviposition. The males arrive at the breeding grounds, before the females, tending to become localized within it i.e they set up territories within which they court females and defend the area from intruding males. Mature males often remain at the rendezvous, making short daily movements to nocturnal roosting sites, unless displaced by strong winds or by aggressive interaction with other males.

For the majority, the rendezvous is at or near the oviposition site, serving as a focus for copulation and subsequent oviposition (Corbet 1980, 1999). This aggregation at oviposition sites can be used as a basis in determining biotope selection. In terms of practical monitoring, the females and pre-reproductive individuals are not always suitable, mostly because they are difficult to identify on the wing, especially African species (Clark and Samways 1996). Pre-reproductive individuals often move away from the breeding ground to feed and mature, and therefore have no reliable association with a specific biotope. In this study, the males are used because they are conspicuous and usually easily-identified on the wing using binoculars.

1.4 The value of Odonata in conservation

Dragonflies have little direct economic importance (Corbet *et al.* 1960). Nevertheless, they remain graceful subjects enhancing the aesthetic nature of landscapes. Their value lies more in the realm of bioemphathy and utilitarian aesthetics rather than in pragmatic biodiversity conservation (Samways 1993). For this reason, reserves have been created for them especially as they give pleasure and are heuristically valuable for education with respect to studies in animal behaviour. Dragonflies are also culturally important, especially in Britain, Germany and Japan (Moore 1987, 1991a, 1997; Corbet 1999).

1. 5 The concept of greenways

1. 5.1 Definition

Greenways or green networks are natural, or permanently variegated, physically-connected spaces situated in areas otherwise built-up or used for intensive agriculture, industrial purposes or other intrusive human activities. They may include land to which there is no general access, such as private gardens and estates. They are, as Forman and Godron (1981) suggest, characteristic of landscapes "bearing the heavy imprint of human activity". Greenways with multiple uses and values in urban areas, go beyond the early ideas that they are important simply for recreation and beauty.

They also address the needs of wildlife, flood control, improved water quality, outdoor recreation, outdoor education, community cohesion, local transport and many other urban infra- structural needs (Council of Europe 1989; Countryside Commission 1991; Forman 1991). This basic approach has been developed in many densely-populated countries of the northern hemisphere. In Britain for example, much land is used for purposes other than agriculture and forestry. This land includes many different types of sites e.g botanical gardens, parks, sports grounds, unoccupied parts of industrial estates etc., and all have a role or a potential role in improving habitats for wildlife (Fry and Londsdale 1991).

Here, many parks already feature butterflies and dragonflies in their nature trails, alongside other interpretive and educational presentations. There is also scope for more emphasis on other types of invertebrates which are not already enjoying popularity.

1.6 The concept of protected areas

Moore (1997) has proposed the establishment of protected areas (e.g. National parks and nature reserves) as one aspect of the basic strategies outlined in a dragonfly conservation Action Plan. These strategies must, among other measures, be supported by the education and raising of public awareness.

1.6.1 Definition

Protected areas are established to protect species or ecosystems from developments which would endanger them. They are places where conservation is the primary land-use, although in many, tourism, research and even some forms of agriculture and forestry, may be important secondary land-uses. Protected areas have been selected for a wide range of reasons including the protection of outstandingly beautiful landscapes, big game, threatened habitats and species.

The conservation of dragonflies has rarely been the primary purpose of establishing protected areas. Japan, where dragonflies have a special cultural significance, provides a notable exception, with more than 24 protected areas established primarily for this order of insects (Eda, 1995; Corbet 1999).

In Britain, three to four reserves have been set up, notably the Ashton Water Dragonfly Sanctuary designed principally to promote interest in dragonflies (Corbet 1993, 1999). Although few protected areas have been established primarily for dragonflies, nearly all protected areas, apart from those in polar and desert regions, support dragonflies (Moore 1997). Some like the Wilson Promontory Natural Park in Australia support a phylogenetically important species, the highly specialized and ancient *Hemiphlebia mirabilis* Sélys (Sant and New 1988). Others support outstanding assemblages of species, notably protected areas in tropical rainforests, for example the Tambopata- Candamo Reserved Zone in Peru, in which over 150 species of dragonflies have been recorded (Butt 1995).

1.6.2 Diversity and conservation status of South African dragonflies

To date, 155 species of dragonflies have been recorded in South Africa; 29 species (18%) are endemic. *Chlorolestes apricans* (Wilmot), *C. draconica* (Balinsky), *Ecchlorolestes nylephtha* (Barnard), *E. peringuueyi* (Ris), *Metacnemis valida* (Hagen), *Pseudagrion inopinatum* (Balinsky), *P. umsingaziense* (Balinsky), *Enallagma polychromaticum* (Barnard), *Ceratogomphus triceraticus* (Balinsky), *Syncordulia gracilis* (Burmeister), *S. venator* (Barnard), *Orthetrum rubens* (Barnard) and *Urothermis luciana* (Balinsky), are ecologically threatened.

Chlorolestes apricans and *U. luciana* are of particular concern. *C. apricans*, whose populations have declined in recent years, appears not to occur in any protected area (Samways 1999). There are several significant sites/areas for Odonata in South Africa. The Western Cape has several endemic species, while the Amatola-Winterberg mountain range of the Eastern Cape has two. The KwaZulu-Natal Drakensberg has the highly localized endemic *C. draconica*. Greater St Lucia is rich in pan-African species, as well as some highly localized endemics. The Kruger National Park has no indigenous species, but is rich in species representing the typical southern African savanna. There are isolated localities such as Itala and Umtamvuna, which have unusual outlier assemblages. However, it is important to note that the presence of rare species in a reserve does not necessarily guarantee their survival. The 1990s have witnessed some huge weather swings due to the vagaries caused by El Niño.

Orthetrum robustum (Balinsky) at St Lucia, *O. brachiale* (P. De Beauvois), *O. gueneense* (Ris) and *O. hintzi* (Schmidt) at Mpenjati reserves were abundant in 1990 but absent in 1994 because the intervening dry years had dried out their pools (Samways 1999).

1.6.3 Threats to dragonflies in South Africa and some conservation management recommendations

Most major human disturbances are harmful to dragonfly population levels especially stenotopic species (k-strategists) Corbet (1999). Exotic tree plantations within 30m of the river's edge reduces species richness, at least in South Africa (Samways 1999). The rainbow trout is implicated in causing range retraction of the very rare and threatened *E. peringueyi*, while removal of natural forest in the southern Cape has eliminated populations of the equally rare *E. nylephtha*. Cattle grazing, resulting in bank vegetation destruction, and black wattle infestations along Eastern Cape river banks have had a major adverse impact on *C. apricans*. These factors are synergistic with lowered water levels in causing population fragmentation. However, not all anthropogenic disturbance is harmful to dragonflies, with some impacts, at least at low levels of intensity, enhancing the numbers of Odonata species, especially eurytopic species (r-strategists), most of which are characteristic of early stages of ecological succession (Corbet 1999) . Small dams play an important role in geographically increasing the overall density of many lentic species (Samways 1989a). Similarly, the aquatic weed *Pistia stratiotes* L. enhances local species richness in the Kruger National Park (Clark and Samways 1996).

Samways (1999), has recommended the following site management measures for conserving South African dragonflies: i) maintaining a constant water level in lakes and reservoirs, ii) encouraging an abundance of aquatic macrophytes, iii) maintaining a wide range of physical bank and shallow water conditions, so that there is a variety of substrate types, vegetation structures and sun/shade conditions.

1.6.4 Botanical gardens as potential reserves for dragonflies

Using Dragonflies in Britain as an example, there were 38 species of Odonata which bred regularly in the seventies until date.

Thirty-six had breeding populations in National Nature Reserves which were selected primarily on botanical grounds by the Nature Conservancy Council (Moore 1976; Ratcliffe 1977; Moore 1991a). Such nature reserves, as well as some botanical gardens therefore, offer ideal micro-habitats, among other important environmental variables, that are useful in designing dragonfly awareness reserves. Additionally, the fact that management of these botanical gardens are placed in the hands of conservationists, means that such reserves are rescued to some extent from commercial and other external pressures. However, they must not be seen as substitutes for pristine habitats. Furthermore, their area is generally rather small, and may not be able to withstand the harsh conditions in years with adverse weather. Also, as the populations are small, genetic bottlenecks may occur.

1.6.5 Support measures for dragonfly conservation

Education and raising of public awareness

Adequate site protection, based on sound legislation, planning and adequate pollution control, can only occur when enough people support the measures required. Therefore, education and raising of public awareness concerning dragonflies is crucial in achieving conservation goals (Moore 1997). Education should teach children and adults alike to value wildlife. Dragonflies, thanks to their conspicuousness and beauty, provide great opportunities for interesting people in nature. They 'stand in' for smaller, more obscure insects. Machado (1989) has taken up this opportunity of educating the public about dragonflies with great success.

Urban dwellers find it difficult to realize that such insect species depend on their wild habitats for survival. This message needs to be emphasized continually as regards dragonflies as well as other wildlife (Moore 1997). Ponds and trails are increasingly used to introduce children and some adults to biological principles. What children learn today will influence how they will react tomorrow to the increasing environmental problems of the world. Once education and awareness-raising has fostered an interest in wildlife and its conservation, a growing demand for advice develops. This can be provided by advisers from statutory conservation organizations, agricultural departments and voluntary conservation bodies (Moore 1997). To this level, the British Dragonfly Society has produced leaflets on pond construction and management of habitats

for dragonflies which can be used by advisers and others who wish to have specific advice about the conservation of dragonflies (British Dragonfly Society 1993).
In this study, a survey will also be carried out to assess the level of public awareness to dragonflies.

1.7 Rationale of this study

Subsection 5:3:4 of the IUCN Status Survey and Conservation Action Plan: Dragonflies has strongly emphasized on the education and raising of public awareness as a support measure for conserving dragonflies and their habitats.

Recently, there has been considerable interest in creating dragonfly reserves in the Northern Hemisphere, mostly with the aim of promoting public awareness, as well as in some cases for conserving of specific species. This trend has been particularly strong in Japan and has been developing in Britain and Germany. In contrast, there appears to be no dragonfly awareness reserves in the Southern Hemisphere.

South Africa has a rich and often localized dragonfly fauna, many parks and botanical gardens that aim to conserve biodiversity, including dragonflies and their habitats. There are however, no areas or trails specifically designed to promote public awareness of dragonfly biology, diversity and conservation. Such dragonfly areas or trails need not necessarily be for conservation of specific target species. Rather, they aim to introduce the public to a spectrum of species living in a series of closely situated habitats with different ecological characteristics. The main characteristics include aquatic permanency, openness and flow rate, vegetation physiognomy and thermal conditions of shade and light intensity. Such a reserve or trail needs also to be reasonably aesthetic to ensure public visitation.

The National Botanical Gardens in Pietermaritzburg offers great potential for designing such a trail, as it has a tapestry of streams, ponds, a dam and adjoining marshland and a river/cascade which together make a highly heterogenous landscape with a wide variety of habitats. In addition, the gardens are at the edge of a major escarpment, so recruiting faunal elements from both higher and lower elevations. This has given rise to an exceptional variety of dragonfly species at one

location.

Furthermore, dragonflies are a focal insect taxon, popular among amateur naturalists and children. They are brightly colored, readily accessible and often seen on sunny days. For this reason, they are good subjects for a nature trail.

1.8 Aims of this study

The specific aim here is to establish an easily walkable trail that encompasses the maximum number of Odonata species.

Specific objectives

i *A priori* selection of 20 habitats within the garden and classify them in terms of Odonata species richness and assemblage patterns.

ii Establish the spatial distribution of dragonfly species, and determine, as far as possible, the biotic as well as the abiotic factors governing the distribution of each.

iii Identify and assess the seasonal changes in population densities, and assemblage compositions.

iv Interview visitors to the botanical gardens to ascertain their level of interest in dragonflies and their conservation.

v Use the above information to enhance public awareness on Odonata species and their conservation by developing a dragonfly trail.

CHAPTER 2

SITE AND METHODS

2.1 Site

Pietermaritzburg National Botanical Gardens (see Fig. 1), located at 29°35' S and 30°25' E at an altitude of 690m a.s.l., was the site chosen for this study because they represent an environmental gradient from a fast-flowing river (the Dorpspruit), slow-flowing stream, ponds, a large dam and adjoining marshland. Breeding of dragonflies at sites is usually confirmed by presence of larvae, emergence, exuviae and observation of oviposition activity (Clark *et al.* 1990, Steytler and Samways 1994). The presence of larvae, tenerals, exuviae and oviposition activity have been observed at the botanical gardens.

2.2 Sampling

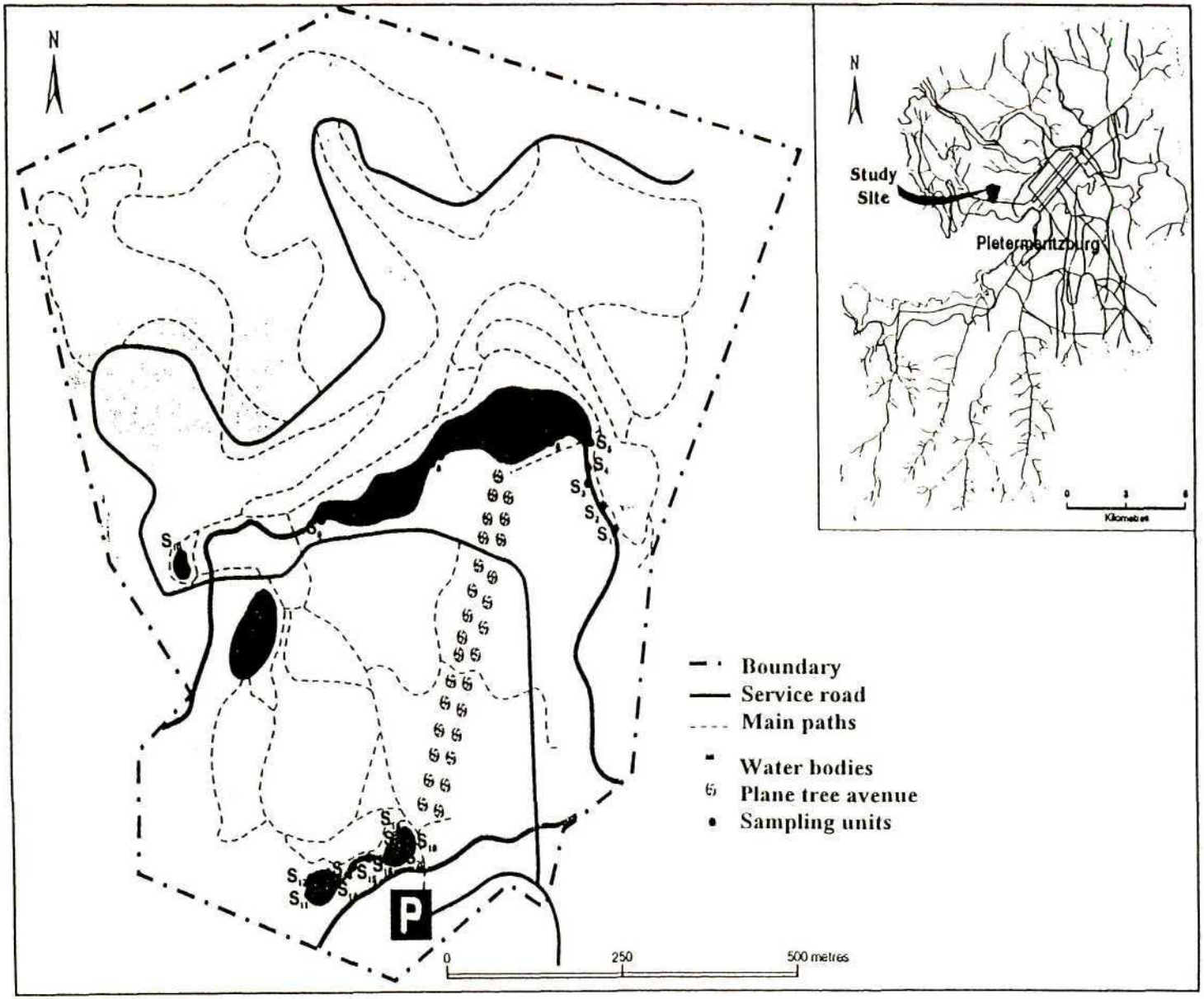
2.2.1 Sampling design

The method of stratified sampling was used to ensure homogeneity in sampling units, such that estimates of adult population means and totals were as precise as possible (Thomson 1992). The site was stratified into 20 sampling units (SUs) each of 10m x 2m (i.e 10m length of water's edge by 1m width on bank and 1m width into water).

2.2.2 Sampling of adult dragonflies

Weekly visits are necessary for maximum accuracy of relative abundances (Moore 1991). Brooks (1993) suggests that sampling should only be done when conditions are best for dragonfly activity. Sampling was mostly weekly, (depending on weather) from May 1998 to April 1999 to ensure the detection of any population changes with season. Adults were sampled by walking the 10m sampling units and recording in 6 min, any individuals patrolling or perching within a sampling unit. Recording was before and after midday when most territorial males were active (Corbet 1993).

Fig 1: Map of project site: The National Botanical Gardens, Pietermaritzburg



Moore (1991b), commenting on the accuracy of this type of sampling, states that the presence of the observer walking through the habitat could cause individuals to leave, or could initiate territorial encounters which could also cause individuals to leave. This could lead to two types of error: i) individuals will leave without being counted and ii) individuals could be counted twice on their return. However, Moore (1991b) expects that counts of Anisoptera at ponds can be taken to be virtually highly accurate, and for the Zygoptera, to be accurate on nearly all occasions. This lower level of accuracy in Zygoptera could be attributed to many small, inconspicuous individuals or counting them twice when densities are high. Based on data collected during most of the study, species occurred most abundantly at the water's edge just before and after noon. Observations in the summer sampling periods showed that most territorial males avoided the hottest peaks of the day. Adults were identified to species level using a pair of 8 x 24 "Olympus" close-focus binoculars. Visual observation of adults gave a highly reliable population estimates. (Southwood 1978; Moore 1991b). Only males were counted, as females are not always in close association with the water and can be difficult to identify in the field. Where identification was uncertain, a net (open diameter 30cm, mesh size 0.5mm) and a 9x hand lens were used to catch and identify them. They were then released, except when they were put into a voucher collection.

2.2.3 Species identification

Mature adults were identified using Pinhey (1951) and Pinhey (1984, 1985). Voucher specimens and the slide collection in the Invertebrate Conservation Research Center (ICRC), School of Botany and Zoology were also referred to. A voucher collection specific to this study was made. Mature adults were identified using body color, genitalia morphology and wing venation.

2.3 Environmental variables and their measurement

Adult dragonflies respond primarily to visual cues. Also, size and shape of water body may be important in habitat selection (Corbet 1962). Larval survival also determines habitat suitability.

*N/B Species names follow Bridges (1994).

Shallow water may be important for larvae because depth of water influences oxygen and prey availability. Dissolved oxygen and temperature influence the development of dragonfly larvae (Corbet 1962, 1999).

Figure 2: Stream Biotope

Many Odonata species prefer water of a certain pH (Weir 1974; Osborn 1992).Water flow may influence oxygen concentration in the water. Vegetation along with substrate may serve many important functions for Odonata (Buchwald 1991; Steytler and Samways 1995; Corbet 1999) e.g. flight perches for food, mating, oviposition and even refuge from predators. The thermal requirements of the species further results in different responses to sunlight and shade.

Against this background, four one-monthly measurements of variables were made in sunny, warm conditions mostly just before and after noon. Water depth was measured using a V.C 1456 meter rule. Acidity (pH) was measured using a Jenway 3405 electrochemistry analyzer calibrated in April before use. Turbidity was only estimated visually at midday as the results became less reliable near dawn or dusk because of reduced surface illumination. The degree of shading of sampling units was estimated by mean % shade cover at midday for each sampling unit. Water temperatures and sampling unit/vegetation temperatures were measured using the Delta Trak hand thermometer at midday. Water temperatures were taken by immersing the mercury bulb by 2 cm below water. Atmospheric temperatures were taken from the botanical gardens daily records. These records were cross checked with readings from the hand thermometer for each sampling day.

2.3.1 Habitat description

Following Howard-Williams (1980), classification, vegetation varied in summer from submerged, semi-aquatic and emergent plants through marginal grasses and sedges to deciduous forest, and showed marked variation in species richness and diversity. Winter was characterized by a drop in level of water (especially in ponds and the stream) and a great reduction in biomass and species diversity of marginal and floating vegetation structure. Habitats were therefore best characterized by amount of open water and vegetation cover (Samways, and Steytler, 1995) into six categories:

i.) RIVeg Fast stony river with herbaceous, forested bank (S1 - S4)

ii) WFVeg Waterfall with grassy, herbaceous and forested banks S5).

Figure 3: Dam Biotope

Figure 4: Waterfall Biotope

Figure 5: St Lucia Widow (*Palpopleura lucia*) in its pond biotope

Figure 6: Glade Jewel (*Platycypha caligata*) in its river biotope

iii) DRVeg Dammed section of river with herbaceous, semi-forested banks and submerged vegetation (S6 - S9)

iv) SPPVeg Semi-permanent forested ponds with dense, fringing macrophytes and lilies (S10-S14)

v) SOSTVeg Lightly forested, semi-permanent, stony stream with ferns, marginal grasses and herbs (S15 - S16).

vi) OPPVeg Open, permanent pond with long grasses, herbs and lilies (S17 - S20).

Both sets of data (Odonata occurrences and environmental variables) were recorded in data matrices as proposed by Ludwig and Reynolds (1988).

2.4 Multivariate techniques in the investigation of species-environment relationships

2.4.1 Uses in ecology

Multivariate techniques have been in use in ecology since late 1950s (James and McCulloch 1990). They provide statistical methods for the study of data with joint relationships among the variables. Such methods can be considered descriptive although some can be applied in a confirmatory way. In general scientific procedure, descriptive work can suggest causes which can then be formulated into research hypotheses and causal models (James and McCulloch 1990). Research can then be seen to proceed as a combination of descriptive, modeling and experimentation. Researchers can describe the pattern of relationship among objects by:
i) classification (the assignment of objects to classes or groups on the basis of inter-object similarities) and ii) ordination (reduction of a matrix of distances or similarities among the objects to one or two dimensions).

2.5 Data analyses

Data were analyzed in two steps: 1) univariate methods for species abundance relationships and 2) multivariate techniques of classification and ordination.

More than one technique was carried out in each step which provided learning experience in various methods of community data analysis in addition to providing an opportunity to compare various methods for confirming the results obtained. Ludwig and Reynolds (1988) and Jongman *et al.* (1987) have recommended the use of more than one method in ecological community data analysis.

2.5.1 Multivariate methods

Classification and ordination methods were used to analyze patterns among the SUs in the whole study area. Multivariate methods have a high summarizing capacity. They are designed to elicit from a quantity of data some internal structure from which hypotheses can be generated. Although ideal for the examination of numerous variables simultaneously, some idea of expected patterns is desirable to avoid generating ineffectual information (Clark and Warwick 1994). Useful texts on multivariable statistics include: Ludwig and Reynolds (1988); Digby and Kempton (1987); James and McCulloch (1990). These methods base their comparisons of samples on the extent to which these samples share particular species at comparable levels of abundance. Similarity coefficients calculated between every pair of samples helps facilitate a classification or clustering of samples into groups which are mutually similar on an ordination plot in which the samples are "mapped" into 2-dimensions in such a way that the distances between pairs of samples reflect their relative dissimilarity of species composition (Ludwig and Reynolds 1988).

2.5.2 Classification

A method of hierarchical agglomerative clustering using the computer program "Cluster" which is in the computer software package PRIMER, an acronym of **P**lymouth **R**outines **I**n **M**ultivariate **E**cological **R**esearch (Clark and Warwick 1994) was used. The species by sampling unit (SU) data matrix was transformed using the 4^{th} root transformation to balance rarer and common species. The Bray-Curtis measure of similarity (Bray and Curtis 1957) was then used on these data to produce a similarity matrix and then fused successively through hierarchical clustering using group average linking. The results of this clustering were represented by a dendrogram with

the x-axis representing the full set of samples and the y-axis defining a similarity level at which two samples or groups are considered to have fused.

Because clustering can be misleading, especially where there is a steady gradation in community structure across sites, perhaps in response to strong environmental gradients, an ordination was therefore carried out using Multidimensional Scaling (MDS) to confirm and describe the community patterns in the study area.

2.5.3 Ordination

Ordination is a term used to describe a set of techniques in which SUs are arranged in relation to one or more coordinate axes such that their relative positions to the axes and to each other provide maximum information about their ecological similarities. When SUs that are most similar or dissimilar are identified based on coordinate positions, underlying biotic and abiotic factors that might be responsible for the observed patterns are determined. Two ordination techniques were employed in this study namely: Multidimentional Scaling (MDS) using the computer software package PRIMER (Clark and Warwick 1994), Correspondence Analysis (CA) and Canonical Correspondence Analysis (CCA) using the computer software package CANOCO, an acronym of **CANO**nical **C**ommunity **O**rdination (Ter Braak 1988). Although CANOCO and PRIMER tackle similar ecological problems, they are different techniques. The computer software CANOCO (Ter Braak 1988) which combines into one logarithm Detrended Correspondence Analysis (DCA) on species data with weighted multiple regression on environmental data was used. CA "extracted" the ordination axes from the species data alone. CA was also used for analyzing temporal species data. Data analyses were done in an exploratory way producing ordination diagrams of SUs species and environmental variables, and then determining which variables best explain the species pattern (Ter Braak 1986, 1988). Monte Carlo permutation tests were then used to determine the degree of significance of a set of environmental variables used to explain species patterns in CCA using CANOCO. MDS analyses using PRIMER were found to be more user-friendly than CANOCO. On the other hand, ordination diagrams produced by CANOCO gave more information in one diagram (samples, species and environmental variables).

2.6 Survey of public awareness (visitors to the botanical gardens)

A questionnaire was designed and used to record responses from visitors to the botanic garden. Essentially the questionnaire determined the extent to which people were: 1) aware of 2) unaware of or 3) indifferent to dragonflies. They were also asked which out of five different presentations (leaflet, guide, poster, photographs, slides) they would prefer to learn more about dragonflies. These findings were a necessary background for designing the dragonfly trail. Fifty individuals were randomly drawn from the visitors to the botanical gardens between December and February 1999. These individuals fell into five age groups : 1-12, 13-19, 20-35, 36- 60, 61+ each of 10 sub-samples. Closed-ended questions were preferred (for reasons of accuracy and precision) to assess the awareness (about dragonflies) and commitment (to know more about dragonflies) levels in these different age groups. The questionnaire was pilot-tested with a few visitors before the definitive one was drawn up. A copy of the questionnaire is given as Appendix 10. Responses were analyzed and are presented graphically for interpretation. Results were used partly to design the dragonfly trail.

2.8 Design of a dragonfly trail

The trail was designed using information obtained from the list of dragonfly species inventoried throughout the study period (May 1998-April 1999), species-biotope preference studies, and from findings from the public survey. The botanical gardens research staff offered essential advice in the practical realities of designing such a trail.

CHAPTER 3

RESULTS

3.1 Changes in species richness and abundance throughout the year

3.1.1 All Odonata species

A total of 5303 individuals of 35 species from 10 families and 2 suborders were recorded during the study period from May 1998 to April 1999. Species occurrences for each month of the study period were recorded in a data matrix (Appendix 1, 4). The cumulative species curve for the whole study area (Fig.7) shows that after February, the curve reaches a near asymptote with 15 Zygoptera and 20 Anisoptera species (Table 1). The changes in Odonata species richness throughout the year are seen in Fig. 8 . Anisoptera species richness in particular increased sharply after October, with lowest species richness in September. Species richness for Zygoptera was lowest in August and highest in March, and with less extremes than the case with Anisoptera.

The highest number of individuals was recorded in February and lowest in July and August (Fig. 9). The total number of Anisoptera individuals steadily increased after August, peaking in February. The total number of Zygoptera individuals increased after July, also peaking in February. The total number of species counts decreased with decreasing individual abundance from May to August. Species counts remained at constant low until November, while individual abundance increased steadily from September to February/March with increase in species counts after October (Fig.10).

3.1.2 Anisoptera species

The pond and stream species *Orthetrum julia* and the pond species *Crocothemis erythraea* were present throughout most of the year, but with very low population counts from August- October and July-August respectively (Appendix 2). Peak abundance of *O. julia* was in February and for *C. erythraea* in October. The pond species *Trithemis arteriosa* was least abundant from June to August, absent in September and October, and then peaked in January.

Table 1. Species list of Odonata recorded during the one-year study period with abbreviations of species names used during analysis.

Species List (Zygoptera)		Species List (Anisoptera)	
Synlestidae	**Abbreviation**	**Gomphidae**	**Abbreviation**
Chlorolestes tessellatus Burmeister	Ctes	*Paragomphus cognatus* Rambur	Pcog
Lestidae			
Lestes plagiatus Burmeister	Lplg		
Protoneuridae		**Aeshnidae**	
Elattoneura glauca Sélys	Egla	*Anax imperator mauricianus* Leach	Aimp
		A. speratus Hagen	Aspe
		A. tristis Hagen	Atri
Coenagrionidae		**Libellulidae**	
Ceriagrion glabrum Burmeister	Cgla	*Orthetrum caffrum* Burmeister	Ocaf
Pseudagrion kersteni Gerstaecker	Pker	*O. julia falsum* Longfield	Ojul
Pseudagrion massaicum Sjöstedti	Pmas	*O. abbotti* Calvert	Oabb
Pseudagrion salisburyense Ris	Psal	*O. trinacrium* Sélys	Otri
Pseudagrion hageni Karsch	Phag	*Nesciothemis farinosa* (Förster)	Nfar
Ischnura senegalensis Rambur	Isen	*Palpopleura jucunda* Rambur	Pjuc
Enallagma glaucum Burmeister	Egla	*Palpopleura lucia* Drury	Pluc
E. elongatum Martin	Eelo	*Crocothemis erythraea* Brullé	Cery
Agriocnemis falcifera Pinhey	Afal	*Sympetrum fonscolombii* Sélys	Sfon
		Trithemis arteriosa Burmeister	Tart
Calopterygidae		*Trithemis dorsalis* Rambur	Tdor
Phaon iridipennis Burmeister	Piri	*Trithemis stictica* Burmeister	Tstr
		Zygonyx natalensis Martin	Znat
Chlorocyphidae		*Pantala flavescens* Fabricius	Pfla
Platycypha caligata Sélys	Pcal	*Philonomon luminans* Karsch	Plum
		Notiothemis jonesi Ris	Nfar
Platycnemididae			
Allocnemis leucosticta Séyls	Aleu		

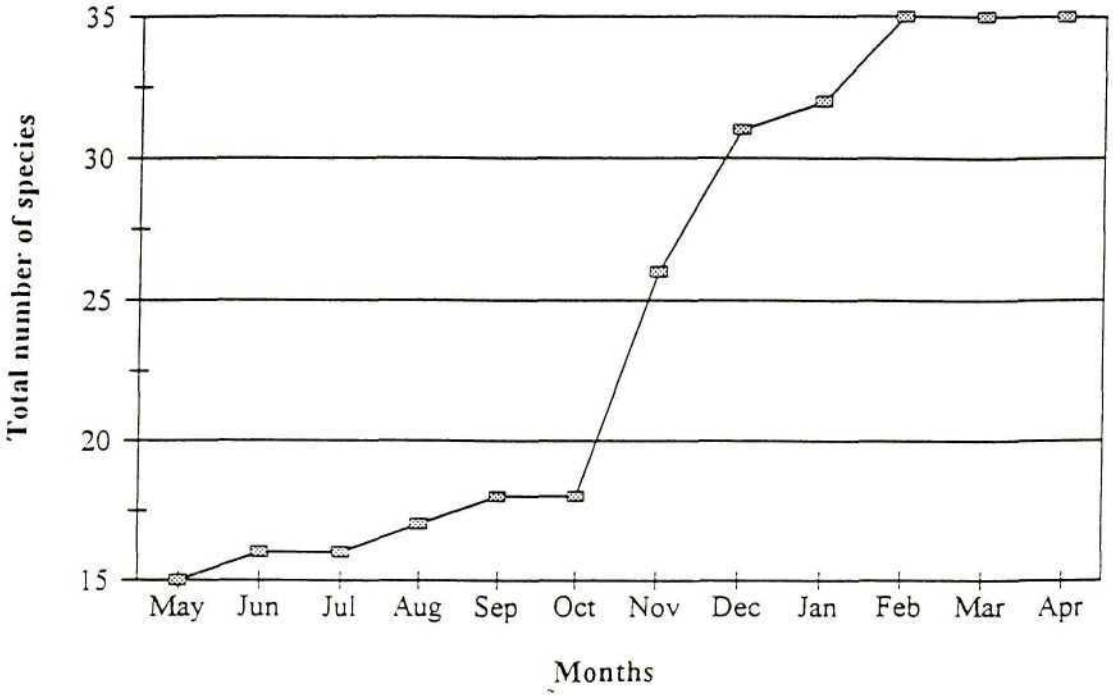


Fig. 7: Cumulative species curve for all Odonata species collected over the one year sampling period.

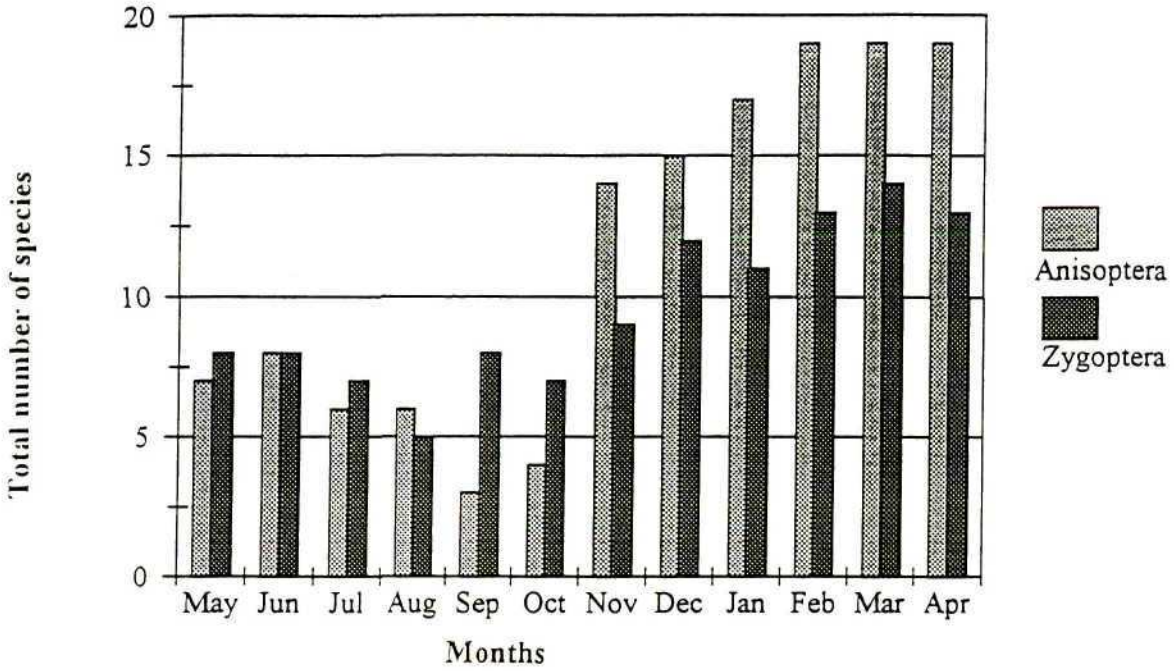


Fig. 8: Total number of Odonata species in all 20 sampling units combined over the one-year sampling period

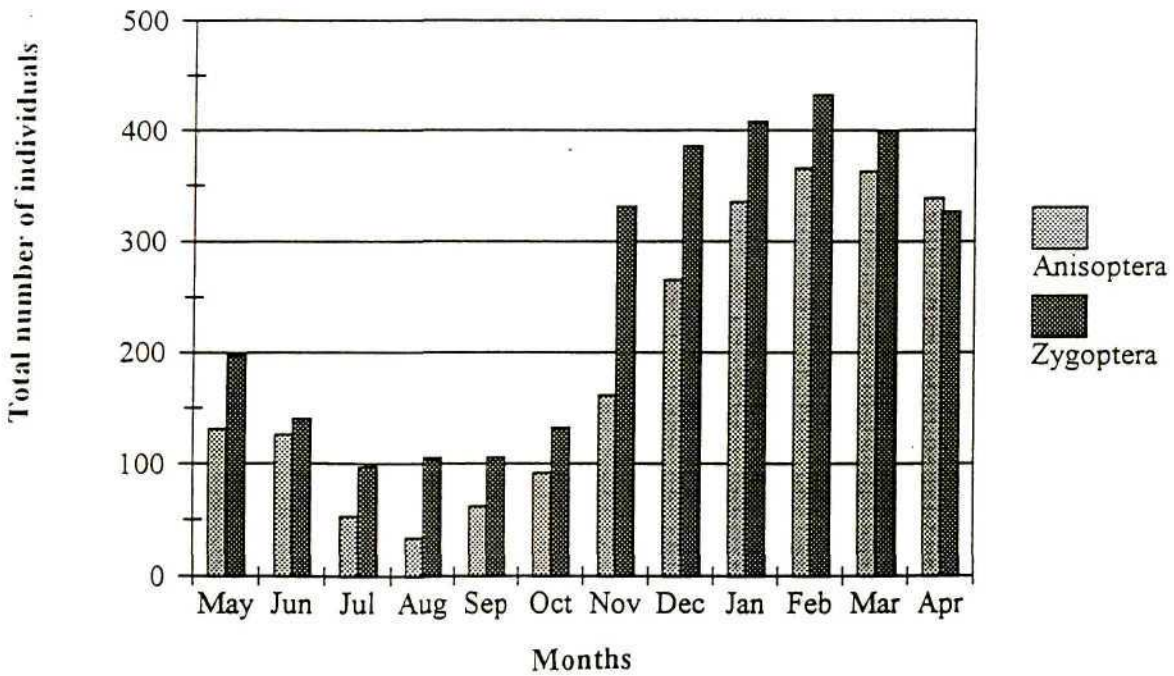


Fig. 9: Total number of Odonata individuals in all 20 sampling units combined over the one-year sampling period.

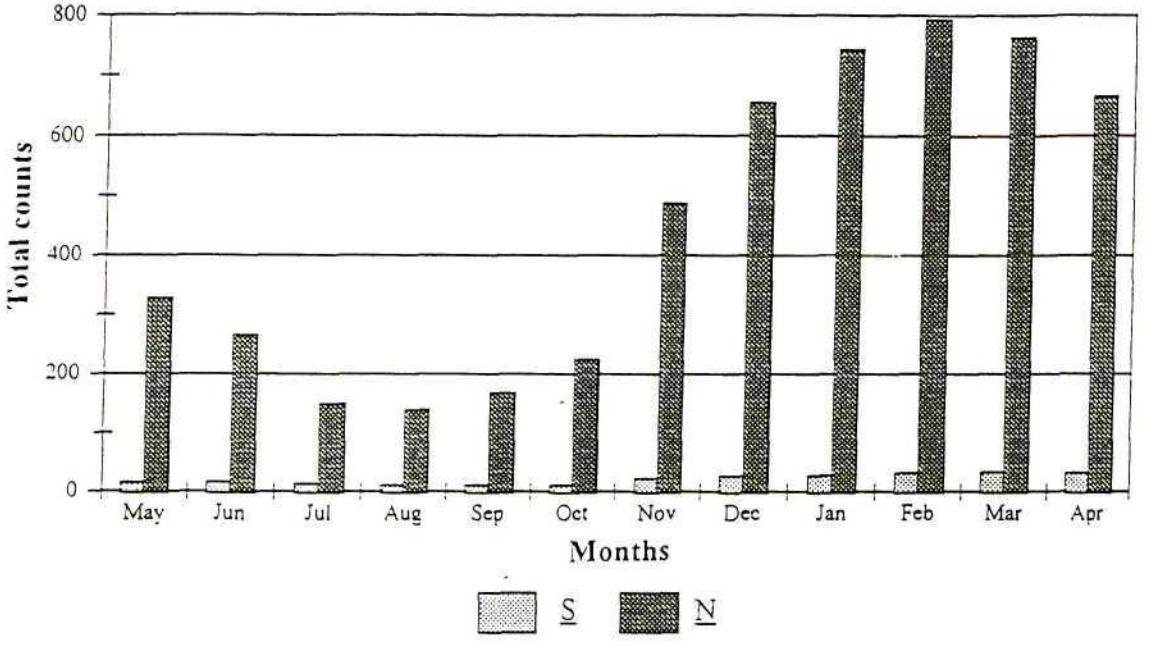


Fig. 10: Total counts of number of species (S) and individuals (N) in each month for the whole sampling period.

Zygonyx natalensis occurred only after November. Other members of this family, especially the pond species, showed a general trend of high abundance from November to April.
The only gomphid recorded was *Paragomphus cognatus*, which appeared only after November. The family Aeshnidae was represented by three species, two (*Anax imperator* and *A. speratus*) of which occurred only at the dam. *A. imperator* made a first appearance in September, with peak population levels in October, and generally high levels from December to April. *A. speratus* showed similar trends, with the first record being in November, and the peak population level in February. There was only one record of *Anax tristis* which was in November. The shade/pond and slow stream species, *Notiothemis jonesi* was present even up to May and June, but then did not reappear until November. Peak counts of this species were from January to March.

The most abundant species was *O. julia*, with a total population count of 549 individuals; mean ($\bar{x}$) = 45.75, ±1SE = 0.32, lowest counts = 3 and highest counts = 90 individuals recorded per month over the entire sampling period. The least abundant species were *A. tristis* (n=1); *S. fonscolombii* (n=4) and *O. abbotti* (n=7) (Table 2 a, b).

3.1.3 Zygoptera species

Most abundant coenagrionids were the pond species *Enallagma glaucum* and the river/stream species *Pseudagrion kersteni* and *P. salisburyense*. These three species were recorded throughout the year, though at very low populations levels from June to September. Peak counts were from January to March (Appendix 3). The pond species *Ceriagrion glabrum* was present throughout most of the year, but rare between July and October, reappearing in large numbers from November to April. Four individuals of the highly localized, lotic species, *Enallagma elongatum*, were recorded March and April. Other populations of species in the coenagrionidae increased after November, peaking from February to April.

Only two individuals of the species *Phaon iridipennis* of the family Calopterygidae were recorded during the whole sampling period. These records were in September. The family Lestidae was represented only by a single pond species *Lestes plagiatus*. It occurred throughout the year but at low levels between June and September.

Table 2. a) Anisoptera species population parameters during the one-year study period
b) Monthly population parameters for Anisoptera species. Lpc = Lowest population count, Hpc = Highest population count.

a) Species	n	Mean ($\bar{x}$)	± 1SE	Lpc	Hpc	b) Months	n	Mean ($\bar{x}$)	±1SE
Orthetrum julia	549	45.75	0.32	3	90	May	131	21.8	0.49
Trithemis dorsalis	111	11.1	0.57	4	21	Jun	126	15.7	0.53
Palpopleura lucia	111	13.8	0.48	1	43	Jul	126	15.7	0.53
Palpopleura jucunda	18	3	0.42	1	6	Aug	34	5.66	0.62
Crocothemis erythraea	428	35.6	0.99	11	63	Sep	62	20.6	0.94
Trithemis arteriosa	265	26.5	0.36	1	51	Oct	88	29.3	0.73
Orthetrum caffrum	12	2	0.34	1	3	Nov	161	11.5	0.34
Notiothemis jonesi	78	7.8	0.36	1	14	Dec	265	17.6	0.35
Anax imperator	60	6	0.33	1	12	Jan	335	19.7	0.35
Nesciothemis farinosa	232	33.14	0.44	1	66	Feb	366	19.26	0.37
Paragomphus cognatus	37	6.16	0.47	1	15	Mar	363	19.1	0.31
Pantala flavescens	107	17.8	0.46	7	38	Apr	339	17.84	0.32
Anax speratus	42	7	0.39	4	9				
Trithemis stictica	256	42.66	0.43	14	68				

Zygonyx natalensis	24	2	0.38	2	7					
Anax tristis	1	1	1							
Philonomon luminans	7	1.4	0.3	1	2					
Orthetrum trinacrium	51	10.2	0.48	2	16					
Orthetrum abbotti	7	1.75	1	1	2					
Sympetrum fonscolombii	4	1.3	0.3	1	2					

Table 3 a.) Zygoptera species population parameters during the one-year study period
b) Monthly population parameters for Zygoptera species. Lpc = Lowest population count, Hpc = Highest population count

a) Species	n	Mean ($\bar{x}$)	±1SE	Lpc	Hpc	b) Months	n	Mean ($\bar{x}$)	±1SE
Enallagma glaucum	707	58.33	0.3	28	115	May	197	24.42	0.39
Lestes plagiatus	476	39.2	0.32	12	74	Jun	140	17.6	0.41
Platycypha Caligata	84	9.77	0.35	2	16	Jul	97	13.3	0.46
Pseudagrion kersteni	220	18.5	0.33	5	41	Aug	105	21.1	0.7
Pseudagrion salisburyense	408	34.3	0.32	9	55	Sep	106	13.2	0.54
Chlorolestes tessellatus	109	12.8	0.47	2	34	Oct	132	18.0	0.58
Allocnemis leucosticta	301	30.0	0.42	1	76	Nov	331	36.6	0.37
Ceriagrion glabrum	428	38.66	0.37	1	80	Dec	386	35.8	0.37
Phaon iridipennis	2	2	1			Jan	408	37.7	0.36
Pseudagrion massaicum	172	14	0.43	19	51	Feb	432	33.4	0.38
Agriocnemis falcifera	27	5.0	0.55	2	14	Mar	400	28.33	0.37
Ichneura senegalensis	61	12.2	0.44	9	16	Apr	327	25.6	0.31
Pseudagrion hageni	60	10.77	0.44	5	20				
Enallagma elongatum	4	2.0	0.7	1	3				
Elattoneura glauca	2	1	1	1	2				

The family Chlorocyphidae included the single river species *Platycypha caligata* which occurred throughout the summer and then into July, and not reappearing again until November. The stream species *Chlorolestes tessellatus* of the family Synlestidae showed a similar trend, where individuals were recorded in October, then reappearing only in February.

The small-stream species *Allocnemis leucosticta* of the family Platycnemididae was on the wing into June, reappearing in October.

The most abundant Zygoptera species was *E. glaucum*, with a total population count of 707 individuals; mean ($\bar{x}$) = 58.33, ±1SE = 0.3, lowest counts = 28 and highest counts = 115 individuals recorded per month over the entire sampling period. The least abundant species were *P. iridipennis* (n=2); *E. glauca* (n=2); *E. elongatum* (n=4) (Table 3 a, b).

3.1.4 Patterns of species diversity and abundance for each month during the study

Appendix 9 gives values of monthly species diversity measures and indices for the whole sampling period. Fig.11 graphs these indices for richness, diversity and evenness using Odonata species data (Appendix 1). It can be seen that species diversity (H'), richness (R1) and evenness (J') varied considerably from one month to the next. High species richness and diversity was observed from November to April, peaking in March. Low species richness and diversity occurred from July to October.

3.2 Changes in species richness and abundance in each of the 20 sampling units throughout the year

Appendix 4, and Fig.12 a, b illustrate the number and abundance of Odonata individuals and species recorded in each sampling unit during the whole sampling period. The number of species increased with abundance from SU1 to SU5, fluctuating from SU6 to SU15 and peaking from SU16 to SU20 (Fig.13).

3.2.1 Proportional abundance

Fig.12 a shows proportional percentage abundance of Odonata individuals in each of the 20

sampling units using data for the whole sampling period.

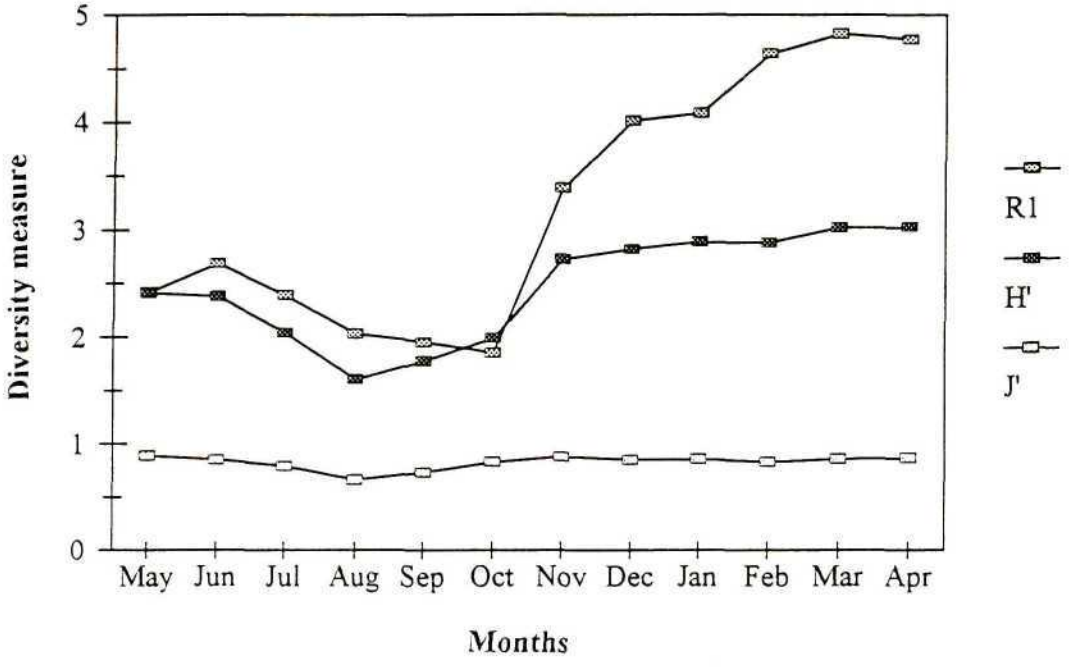
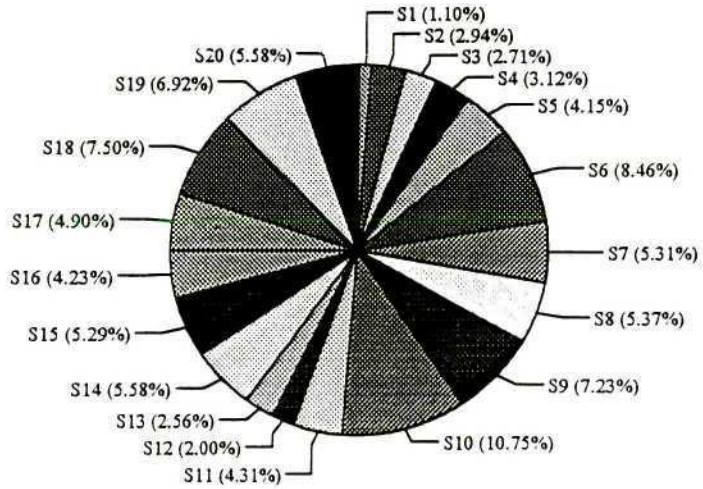


Fig. 11: Comparison of diversity measures of species richness, Margalef's index (R1), Shannon diversity index (H') and Pielou's Evenness (J') shown for each month of the whole study period.

a)



b)

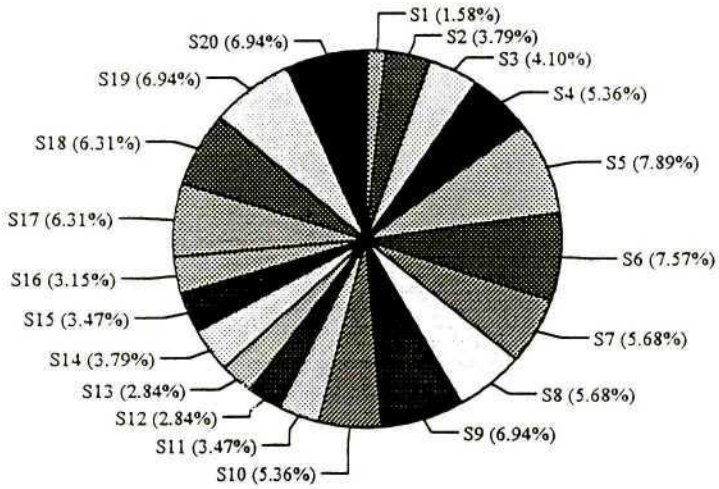


Fig. 12:a) Total number of individuals (5030). b) Total number of species (35) recorded over the whole study area, for one year (May 1998 - April 1999), and shown proportionately for each of the 20 sample units (S1-20).

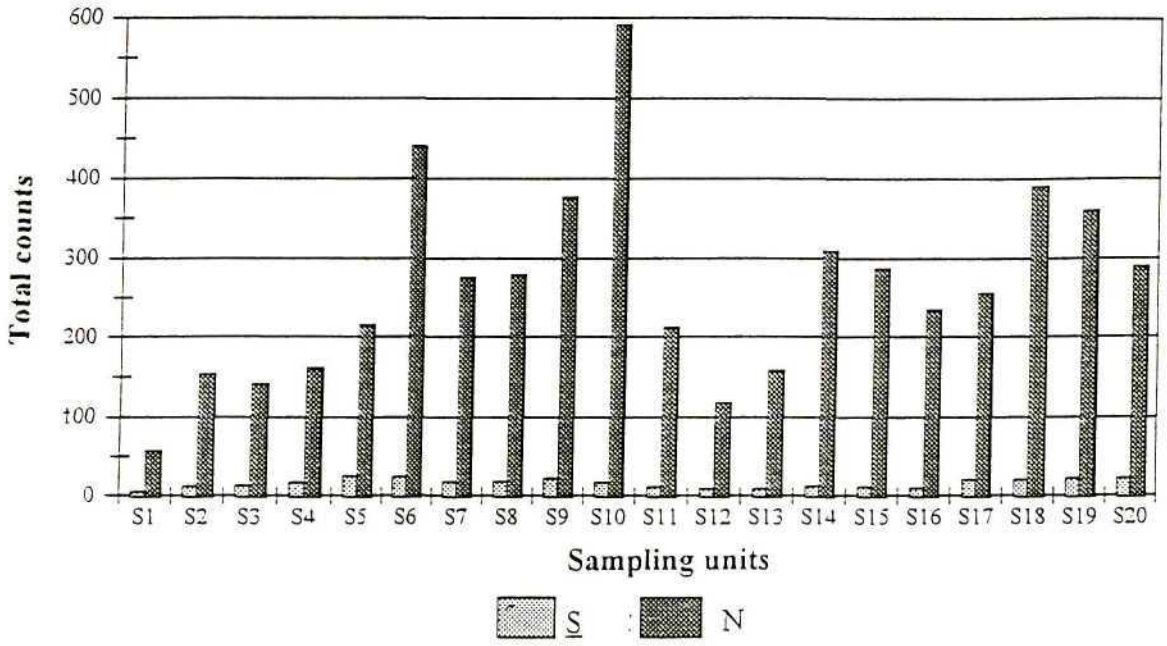


Fig. 13: Total counts of number of species (S) and individuals (N) in each of the 20 sampling units for the whole sampling period.

In order of decreasing number of individual abundance (n), given in brackets for each sample unit: S10 (n=591), S6(n=440), and S18(n=390) were the highest. S3(n=141), S12(n=118) and S1(n=57) were the lowest.

3.2.2 General sample unit species richness

Fig. 12 b illustrates proportional percentage of species in the 20 sampling units using data of the whole sampling period. In order of decreasing number of species (n) in brackets for each of the 20 sampling units: S5(n=25), S6(n=24), S9(n=22), S19(n=22), were the highest and S10 (n=10), S13 (n=9), S12(n=9), and S1(n=5) were the lowest.

The number of species increased with abundance from SU1 to SU5, fluctuating from SU6 to SU15 and peaking from SU16 to SU20 (Fig.13). At suborder level, Fig. 14 a, b compares the populations of Anisoptera and Zygoptera species respectively from each of the 20 sampling units. Sampling units 9, 6 and 5 recorded the highest number of Anisoptera species and SU 16, 15, 13 and 12 the lowest. Sampling unit 5, and 6 recorded the highest number of Zygoptera species while SU1 recorded the lowest.

3.2.3 Patterns of species diversity among sampling units

Appendix 8 gives values of species diversity measures and indices for each of the 20 sampling units for the whole sampling period. Fig.15 graphs these values for species richness (R1), diversity (H') and evenness (J') using Odonata species data (Appendix 4). It can be seen that species richness and diversity varied from one sample unit to another. Overall highest species richness and diversity was recorded in sample unit 5, closely followed by SU 6, 19 and 20.

3.3 Multivariate analyses of species data

3.3.1 Community classification and ordination of sample units using PRIMER

The PRIMER programs cluster and MDS were used to carry out classification and ordination of sampling units through Hierarchical clustering and Multidimensional Scaling respectively.

Figs 16, 17 and 18 show dendrograms from hierarchical clusters of the 20 sample units (1-20), using group-average linking of Bray-Curtis similarities in PRIMER, calculated using 4th root-transformed abundance data for Anisoptera, Zygoptera and "all Odonata species" data (Appendix 5, 6 and 4 respectively).

3.3.2 Analysis of sample unit clusters

Dendrogram for Anisoptera (Fig.16): At 73% level of similarity, 6 ecologically meaningful groupings of sample units were obtained: [1], [2-4], [11-14], [15-16], [5], [6-10,17-20]. Sample unit five was unique since it had a combination of pond, river and waterfall ecological characteristics.

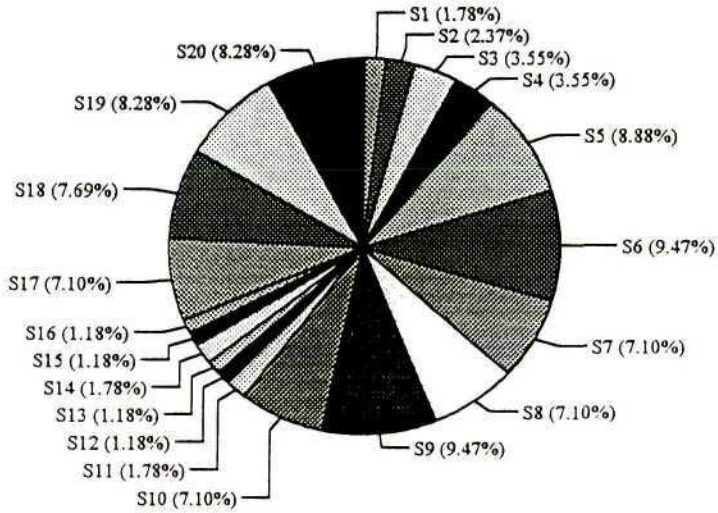
Dendrogram for Zygoptera (Fig.17): At 72% level of similarity, five ecologically meaningful groupings of sample units were obtained: [1], [2-3], [4-5], [11-16], [6-10,17-20]

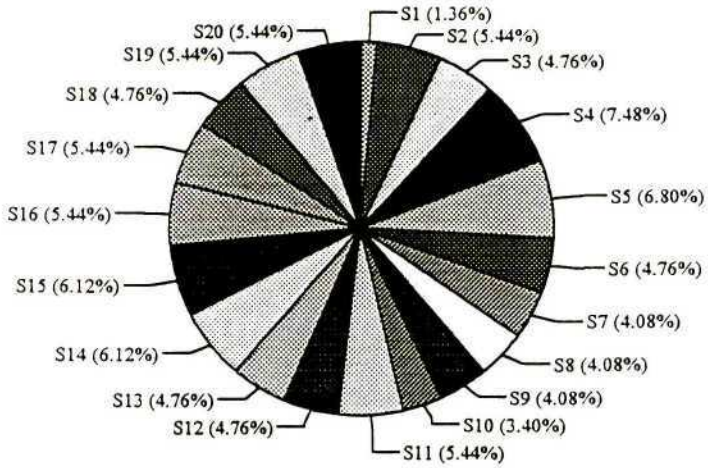
Dendrogram for Odonata species (Fig. 18): At 62% level of similarity, four ecologically meaningful groupings of sampling units was obtained.: [1], [2-5], [11-16], [6-10,17-20].

Each of the three cluster files above was used as an input file to produce ordination diagrams using the MDS program in PRIMER. Figs 19, 20 and 21 were obtained as result files for Anisoptera, Zygoptera and "all Odonata species" respectively. A stress level value of 0.06 each was obtained for the two suborder ordinations. This value implied that the two ordination diagrams (Figs. 19 and 20) were accurate representations of the dendrograms in Figs 16 and 17. An even more accurate representation was obtained when "all Odonata species" ordination diagram (Fig. 21) was used since the stress value in this situation was lower at 0.05.

The fewest (4) ecologically meaningful groupings were obtained at a relatively low similarity level of 62%. The Odonata species data file in PRIMER was therefore further analyzed using the program Simper to detect good discriminator species that could be responsible for creating 4 sampling unit groupings produced in Fig 18. The possible discriminator species are listed in Table 4. Each of these species contributes to the separation of pairs of clusters as average similarity within a group and average dissimilarity between groups. From the sampling unit groupings, a new sampling unit could be assigned to one of four habitat types on the basis of overall species composition, richness and diversity (Appendix 4).

a)





b)

Fig. 14: a) Total number of Anisoptera species. b) Total number of Zygoptera species recorded over one year (May 1998 - April 1999) and shown proportionately for each of the 20 sample units (S1-20).

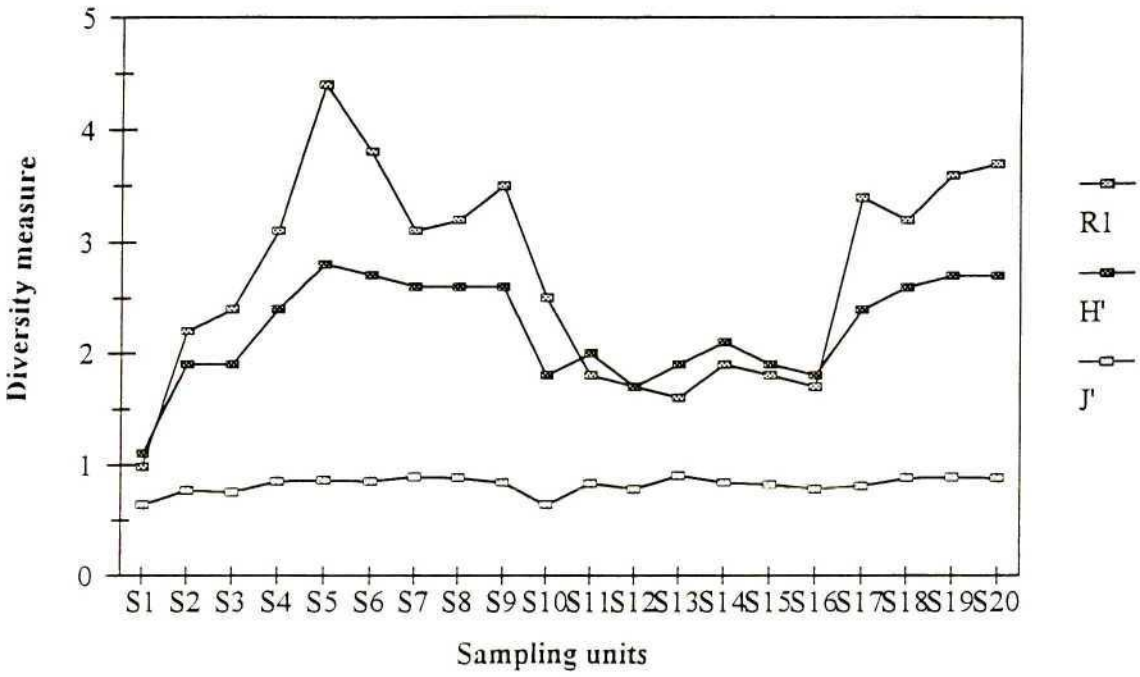


Fig. 15: Comparison of diversity measures of species richness, Margalef's in dex (R1), Shannon diversity index (H') and Pielou's Evennes index (J') for each of the 20 sampling units for the whole study period.

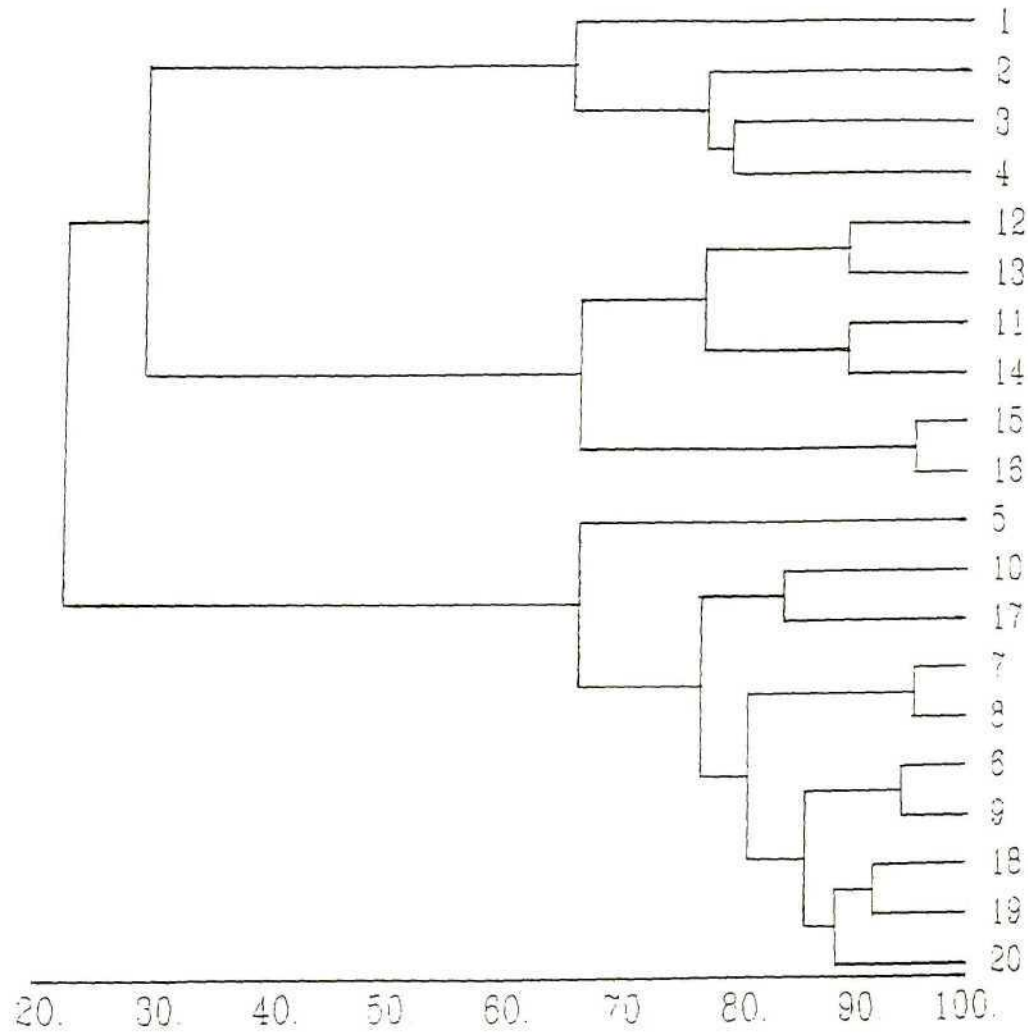


Fig. 16: Dendrogram for hierarchical clustering of the twenty sampling units (1-20), using group-average linking of Bray-Curtis similarity in PRIMER, calculated on 4th root-transformed abundance data for Anisoptera species.

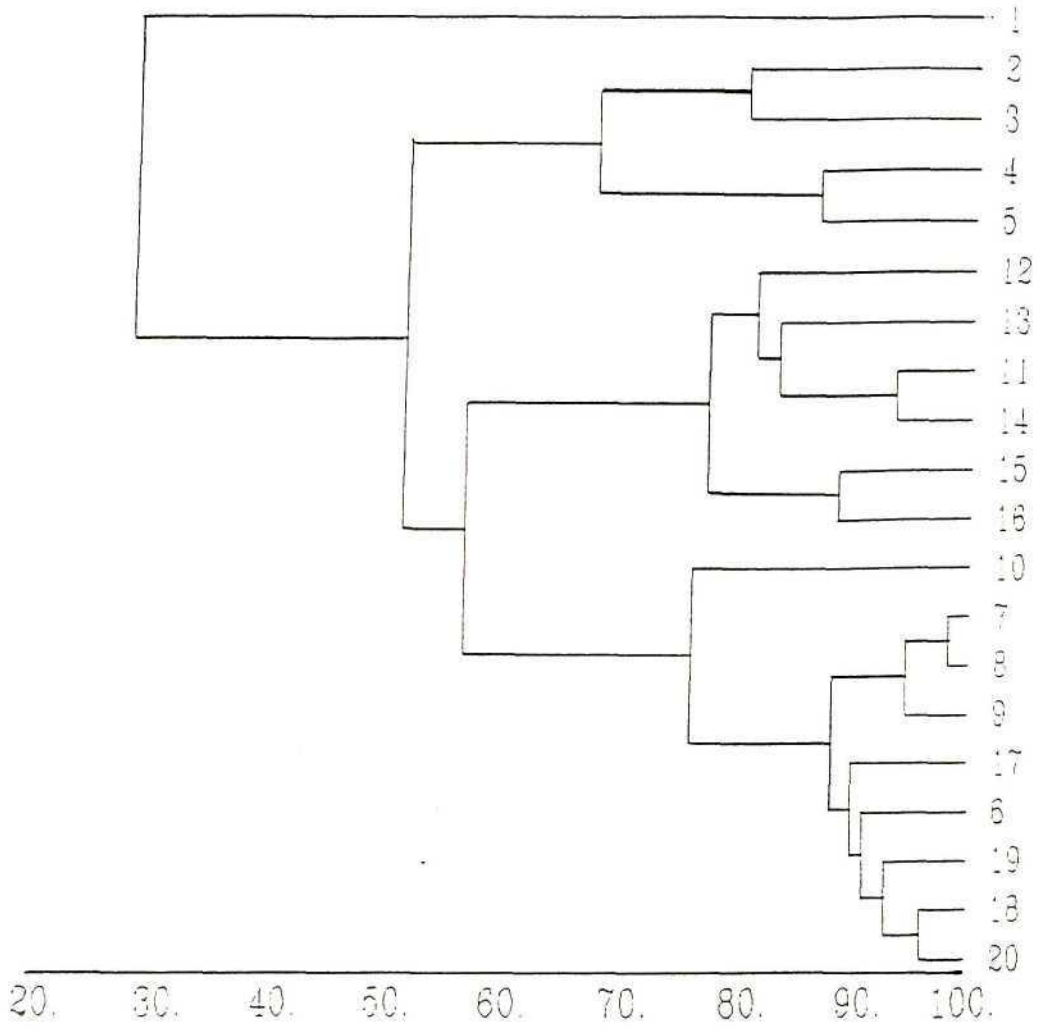


Fig. 17: Dendrogram for hierarchical clustering of the twenty sampling units (1-20), using group-average linking of Bray-Curtis similarity in PRIMER, calculated on 4th root-transformed abundance data for Zygoptera species.

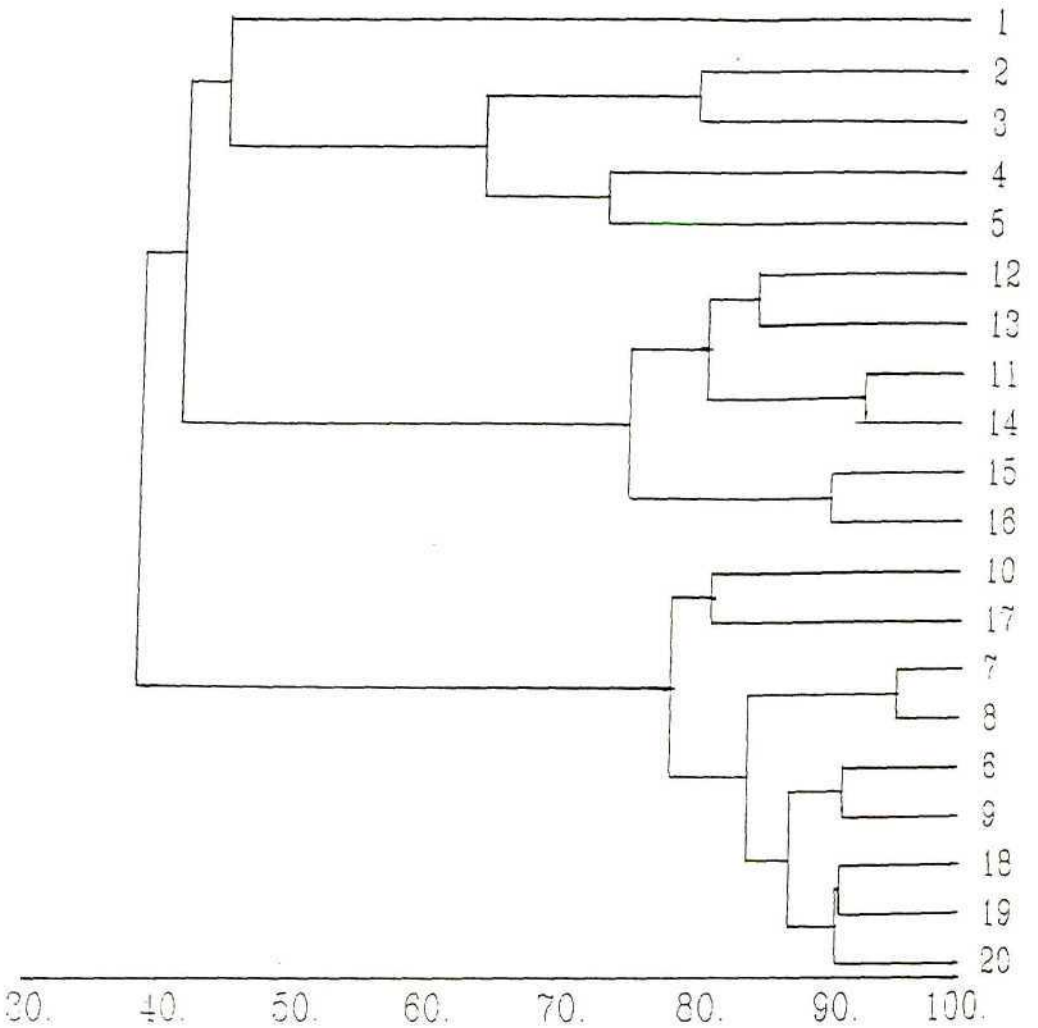


Fig. 18: Dendrogram for hierarchical clustering of the twenty sampling units (1-20), using group-average linking of Bray-Curtis similarity in PRIMER calculated on 4th root-transformed abundance data for 'all Odonata species'.

3.3.3 Classification of sampling units and associated Odonata species

Below is a summary of the characteristic features and species present in the four resultant habitat types:

Group 1 : SU1

Biotope description:

Open, stony meandering section of river (spillage from dam) with grassy banks.

Characteristic species:

P. salisburyense, Z. natalensis, P. kersteni

Group 2 : SU2, SU3, SU4, SU5.

Biotope description:

Shaded stony meandering river with herbaceous, grassy banks and indigenous forest four meters away. A 2.5 metre high waterfall with fringing herbs and grass e.g the broad-bladed grass *Setaria megaphylla* species.

Characteristic species:

A. leucosticta, Z. natalensis, P. cognatus, T. dorsalis,P. caligata, P. saliburyense, P. kersteni, C. glabrum, E. elongatum, E. glaucum, L. plagiatus, A. falcifera.

Group 3 : SU11, SU12, SU13, SU14, SU15, SU16.

Biotope description: Highly shaded, semi-permanent pond with dense, fringing macrophytes giving rise to a shady semi-permanent stream with ferns, overhanging trees, grasses and herbs.

Characteristic species:

C. tessellatus, A. leucosticta, P. hageni, N. jonesi, E. glaucum, P. salisburyense, P. kersteni, C. glabrum.

Group 4 : SU6-SU10. SU17-SU20.

Biotope description:

Open, permanent ponds (SU10 highly seasonal) with marginal grasses and herbs. Reeds, water lilies and other aquatic vegetation present at SU10, SU17-SU20. Submerged vegetation and adjoining marshland present at the dam sampling units SU6-SU9. Opposite side of dam is made up of indigenous forest.

Characteristic species:

C. erythraea, T. arteriosa, N. farinosa, E. glaucum, A. speratus, A. imperator, P. massaicum, T. stictica, C. glabrum, P. kersteni, P. salisburyense, I. senegalensis.

3.4 Ordination of sample unit data using CANOCO

3.4.1 Correspondence Analysis (CA) biplots of species and sampling units

It was observed that the species data do not have many zeros or high records that needed down weighting. Nevertheless, when both square-root transformed and untransformed data were compared, they gave similar results. It was possible to extract dominant patterns of variation in community composition among the 20 sampling units with data untransformed.

Correspondence analysis was carried out for Anisoptera, Zygoptera and "all Odonata species" data (Appendix 5, 6 and 4 respectively). Monthly species data (Appendix 1) was also ordinated with months (1-12) as sampling units.

3.4.2 Sampling unit CA for Anisoptera

Sampling units 6, 7, 8, 9, 10, 17, 18, 19, 20 (Fig. 22) were very close together with *T. stictica, A. speratus, A. imperator P. flavescens, C. erythraea, T. arteriosa* and *N. farinosa* being the typical dragonfly species here. Sampling units 1, 3, 4, and 5 were equally close together and had similar species like *Z. natalensis, P. cognatus* and *T. dorsalis*. Sampling units 13, 12 and 14 were also similar ecologically, with *N. jonesi* being the dominant species here.

These inferences agree with the data in Appendix 5. Cumulative % variance for the first axis λ_1 = 0.78 and second axis λ_2 = 0.51 was 58.3%.

3.4.3 Sampling unit CA for Zygoptera

Sample units 6-10, 17-20 (Fig. 23) were close together with common species examples as *P. massaicum* (highest counts in SU6), *L. plagiatus* (highest counts in SU18), *E. glaucum* (highest counts in SU10), *P. kersteni* and *P. salisburyense*. Sampling units 2,11-16 were very similar, with species like *P. hageni, C. tessellatus, A. leucosticta*. These inferences correspond with species data. Cumulative % variance for the first axis $\lambda 1$ = 0.56 and second axis λ_2 = 0.34 was 57.7%.

3.4.4 Sampling unit CA for Odonata species

Ordination diagram (Fig.24) attempts to summarize the information in Figs 22 and 23. Cumulative percentage variance for the first axis $\lambda 1$ = 0.58 and second axis λ_2 = 0.41 increased to 69.1%. Open pond species in sampling units 6-10,17-20 were quite distinct from the stream/semi-permanent shade ponds in SUs 11-16 and river SUs 1-4. 'Eurytopic' species were located around the centre of the ordination bi-plot diagram. Common species in this group included *O. julia, O. caffrum, C. glabrum* and *E. glabrum, P. salisburyense, L. plagiatus*.

3.4.5 Monthly CA for Odonata

With the 12 months of the year as sample units, the first sampling month (May) was in these analyses the fifth month of the year. November to April were very close together on the ordination diagram (Fig. 25) and showed a marked degree of species richness, diversity and abundance. This agrees with species data (Appendix1). July-October were species poor months with extremes in September and October. Cumulative percentage variance for first axis λ_1 = 0.21 and second axis λ_2 = 0.11 was 65.1%.

In all correspondence analyses, not all species were represented on the ordination diagrams, only the most abundant, and those unique to a sample unit or, rather, the discriminating species, have been shown due to space restrictions.

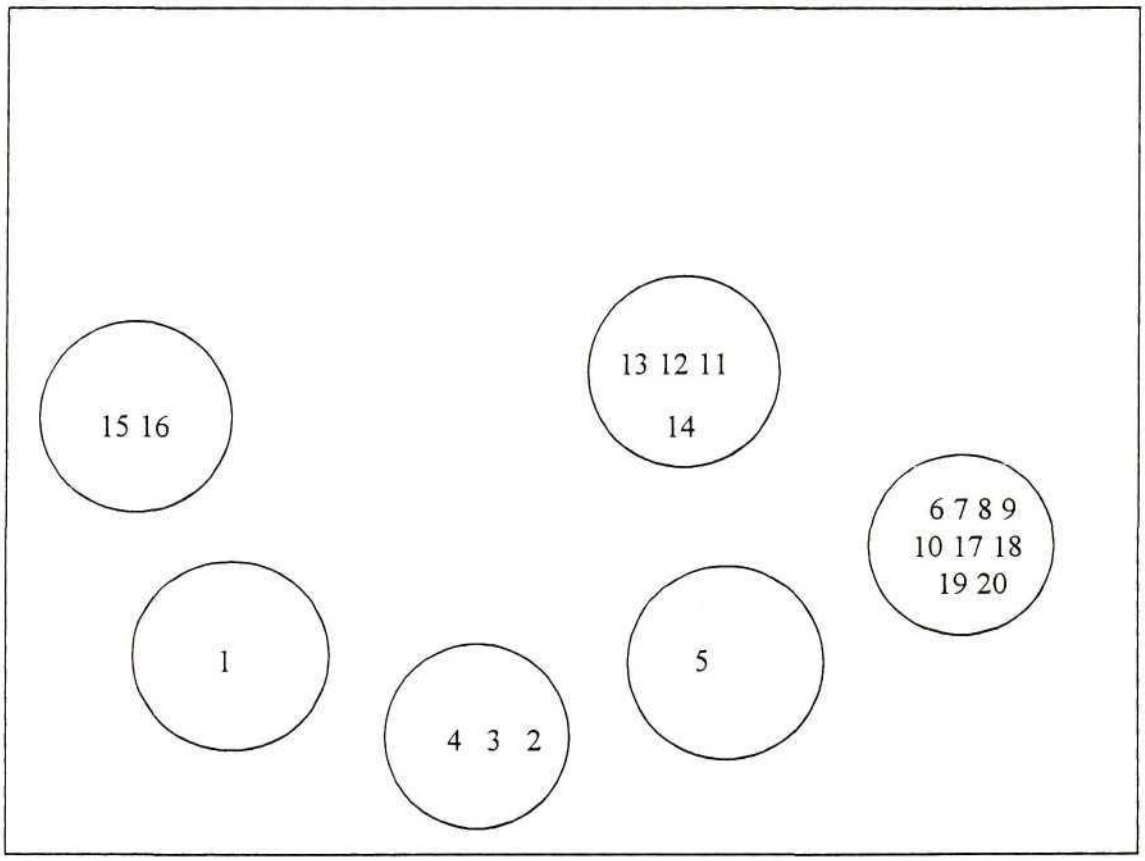


Fig. 19: MDS ordination of the twenty sampling units (1-20) based on 4th root-transformed abundance data and Bray-Curtis similarity for Anisoptera species using PRIMER. (Stress = 0.06).

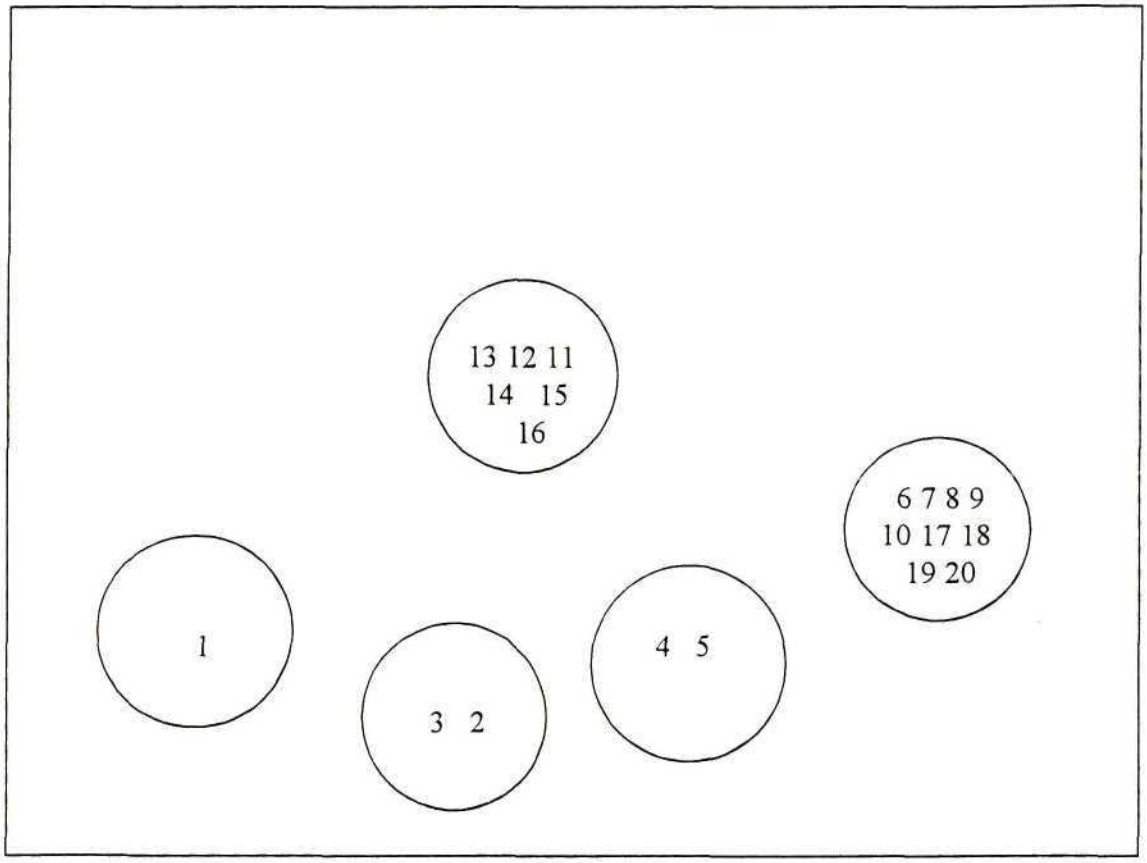


Fig. 20: MDS ordination of the twenty sampling units (1-20) based on 4th root-transformed abundance data and Bray-Curtis similarity for Zygoptera species using PRIMER. (Stress = 0.06).

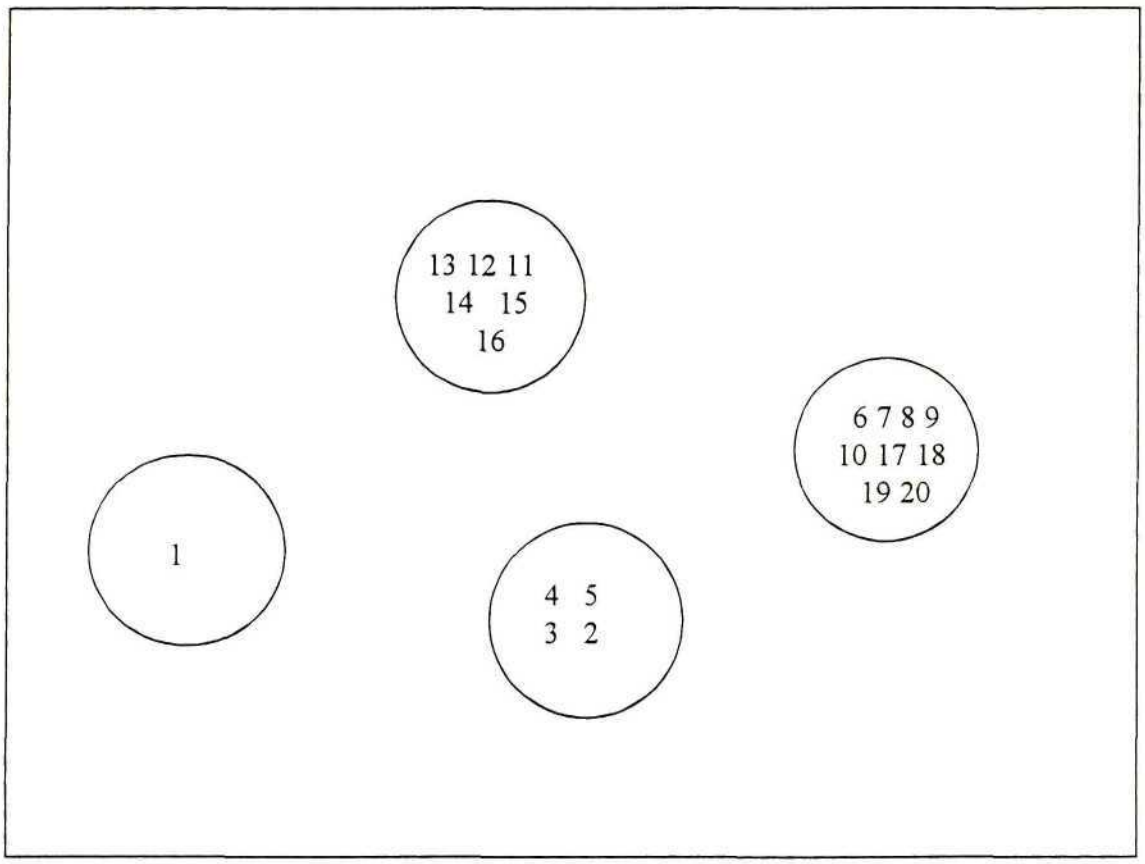


Fig. 21: MDS ordination of the twenty sampling units (1-20) based on 4th root-transformed abundance data and Bray-Curtis similarity for 'all Odonata species' using PRIMER. (Stress = 0.05).

Table 4. Discriminator species for sampling unit groups. (These species are good discriminators of groups produced by a cluster analysis (Figs 16- 18) and MDS analysis (Figs 19 - 21). These results were obtained using the program Simper (% similarity) in PRIMER which calculates contributions from each species to the separation of pairs of clusters as average similarity within a group and average dissimilarity between groups).

Group	Size	Sampling units	Average % similarity	Descriminator species	Average % dissimilarity	Discriminator Species
1	5	**1, 2-5**	58.8	Psal, Znat, Aleu, Ojul, Tdor	41.2	Pcal, Lplg, Pcog
2	10	**2-5, 11-16**	58.5	Aleu, Ojul, Psal, Pker, Eglm, Cgla Phag, Lplg	41.5	Ctes, Pcog, Znat, Pcal
3	7	**1,11-16**	66.1	Ojul,Aleu,Psal	33.9	Znat, Ctes Lplg, Phag
4	10	**1, 6-10,17-20**	70.2	Psal, Ojul	29.8	Cery, Znat Nfar, Aleu
5	13	**2-5, 6-10,17-20**	63.1	Eglm, Psal, Pker Ojul, Lplg, Cery, Tart, Pfla, Tdor, Isen	36.9	Aimp, Aspe, Nfar, Pcog, Znat, Pcal
6	15	**11-16, 6-10,17-20**	59.7	Cgla, Ojul, Eglm Lplg, Psal, Pker	40.3	Cery,Ctes, Aleu,Tart, Nfar

See Table 1 for meaning of abbreviations

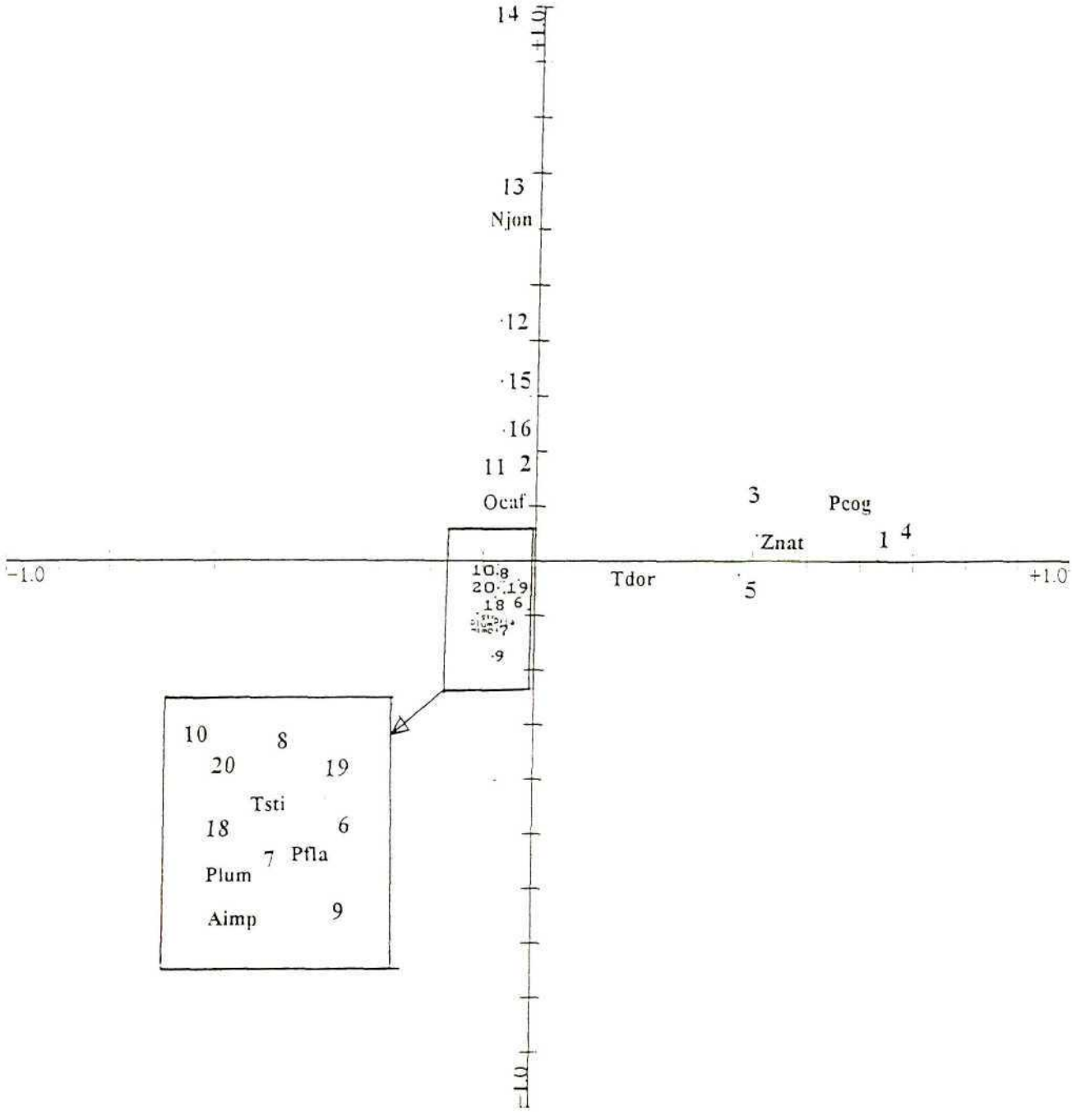


Fig. 22: Ordination diagram of correspondence analysis (CA) using Anisoptera data (Appendix 5). The first axis $\lambda_1 = 0.781$ is horizontal and the second axis $\lambda_2 = 0.509$ is vertical. The diagram shows the distribution of species among the 20 sampling units (1- 20 shown in bold type numbers). The species names are abbreviated (see Table 1). The program. CANOCO was used.

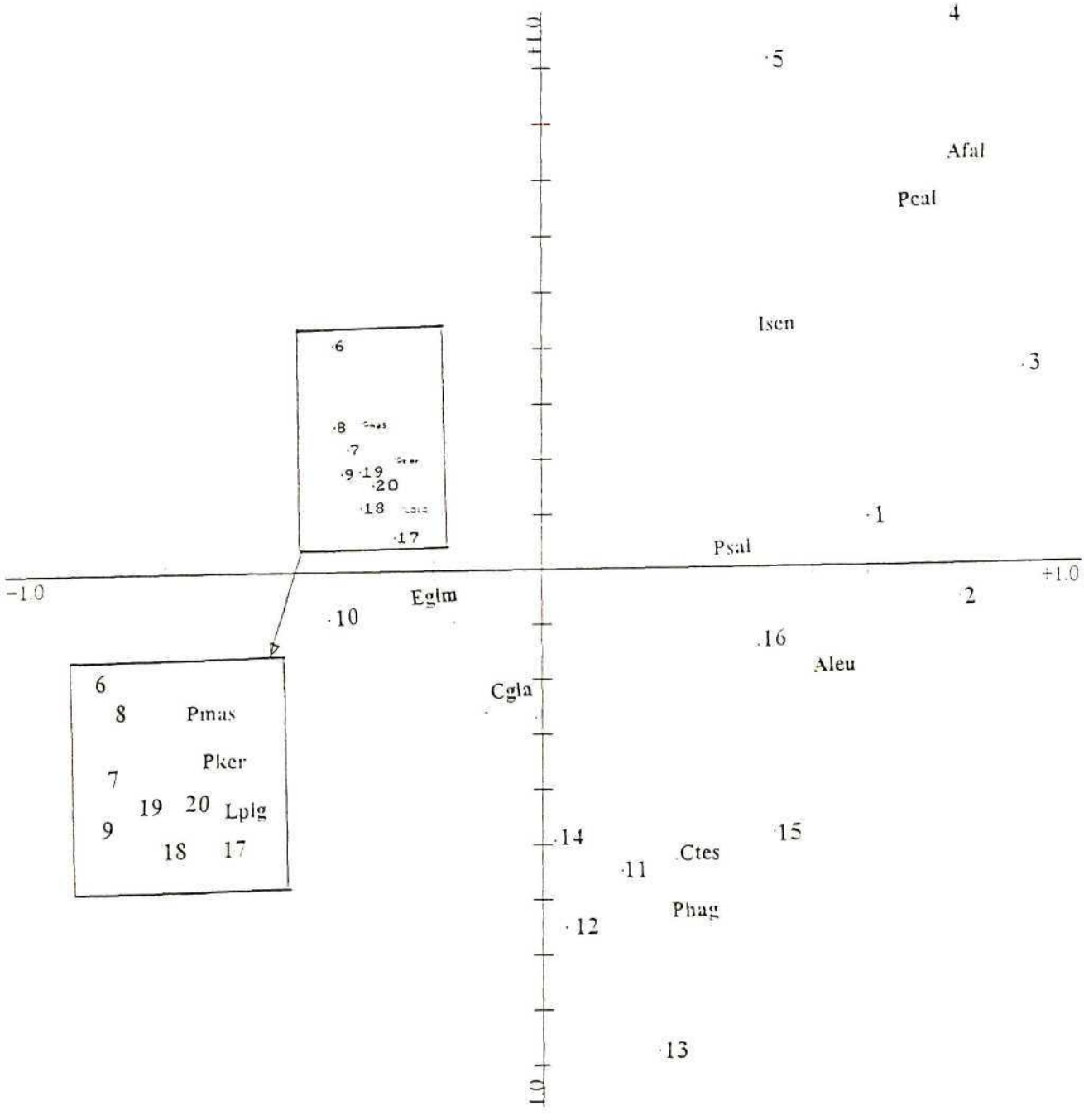


Fig. 23: Ordination diagram of correspondence analysis (CA) using Zygoptera data (Appendix 6). The first axis $\lambda 1 = 0.557$ is horizontal and the second axis $\lambda_2 = 0.335$ is vertical. The diagram shows the distribution of species among the 20 sampling units (1-20 shown in bold type numbers). The species names are abbreviated (see Table 1). CANOCO was used.

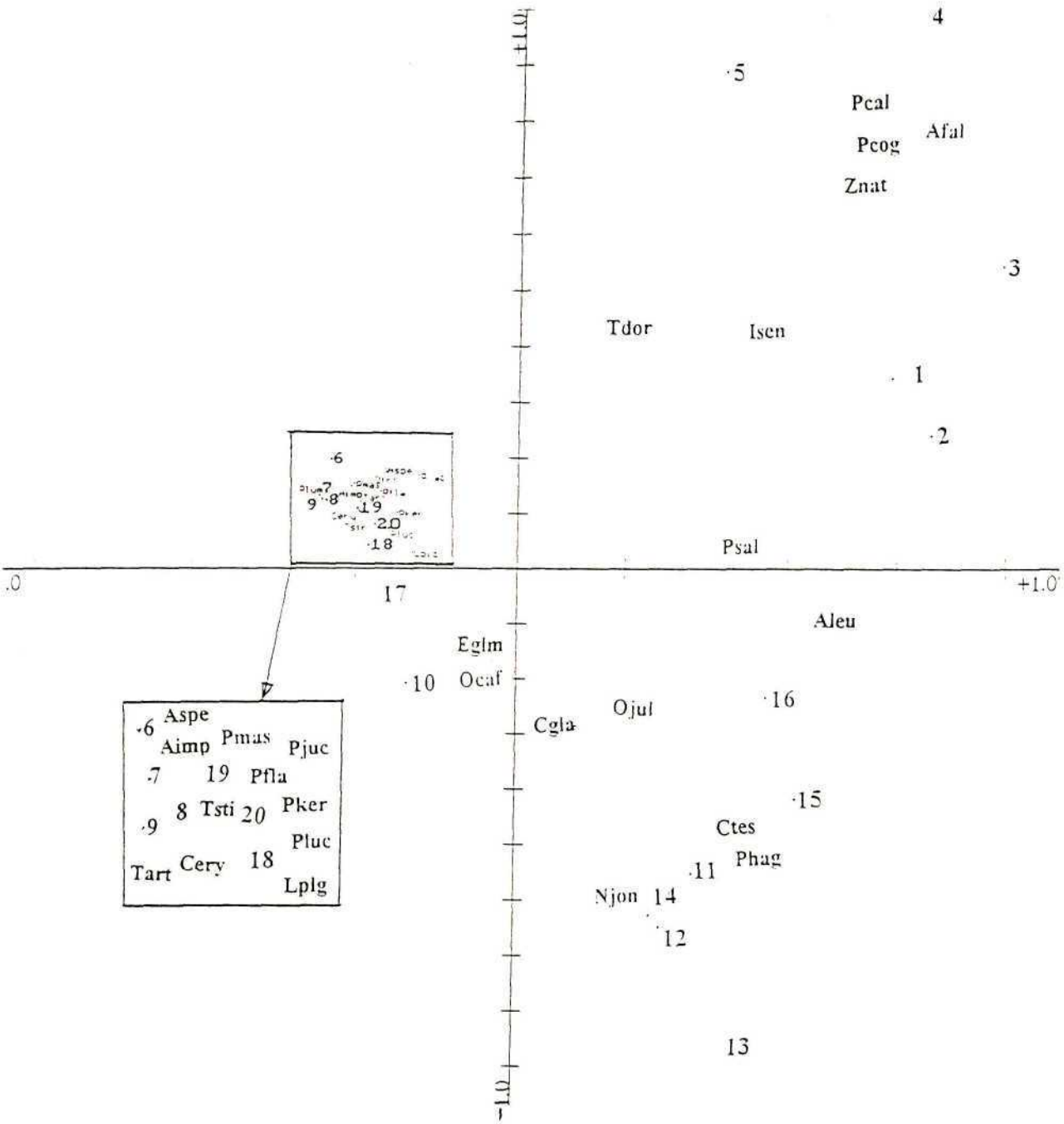


Fig. 24: Ordination diagram of correspondence analysis (CA) using 'all Odonata species data (Appendix 4). The first axis $\lambda_1 = 0.584$ is horizontal and the second axis $\lambda_2 = 0.411$ is vertical. The diagram shows the distribution of species among the 20 sampling units (1-20 shown in bold type numbers). The species names are abbreviated (see Table 1).CANOCO was used.

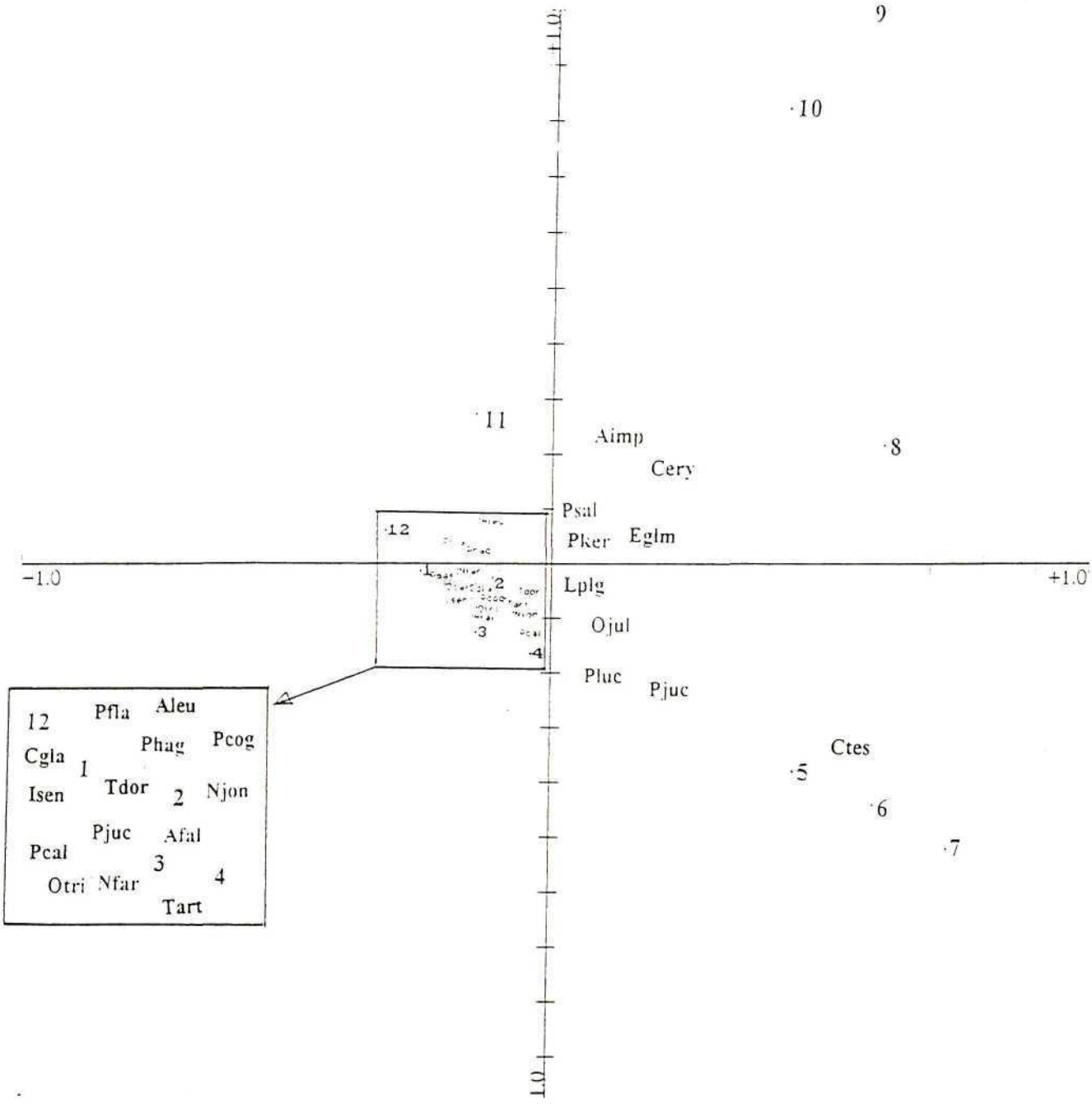


Fig. 25: Ordination diagram of correspondence analysis (CA) using Anisoptera and Zygoptera data (Appendix 1). The first axis $\lambda_1 = 0.207$ is horizontal and the second axis $\lambda_2 = 0.106$ is vertical. The diagram shows monthly distribution of Odonata species for the twelve months (1-12 in bold type numbers) sampling period. The species names are abbreviated (see Table 1). The program CANOCO was used.

3.5 Canonical Correspondence Analysis (CCA) for investigating species-environment relations

CCA was carried out to relate the twelve environmental variables (Section 2.3.1; Appendix 7; Table 5) to sampling unit/species data for each of the two suborders and for "all Odonata species", in each of the 20 sample units for the entire study period. CCA for Anisoptera species gave the highest eigenvalues for the first two axes, while the lowest eigenvalues were obtained for the first two axes for Zygoptera (Table 6). For CCA using Odonata species data, intermediate levels of eigenvalues at $\lambda_1 = 0.58$ and $\lambda_2 = 0.39$ were obtained with the highest cumulative percentage variance at 67.7%. The lowest percentage cumulative variance was for Anisoptera at 63.2% with high eigenvalues of $\lambda 1 = 0.71$ and $\lambda_2 = 0.41$ for the first and second axes respectively. The species points are scattered across a range of ±1 standard deviation units along the first and second axes (Figs 26-28).

3.5.1 Sampling unit CCA for Anisoptera

In ordination diagram (Fig. 26), species-environment correlations for axes: AX1= 0.96 and AX2 = 0.97 (Table 6). Axis 1 was positively correlated with pH, RIVeg, and WFVeg while axis 2 was positively correlated with pH, %Sh, SPPVeg and negatively correlated with water and atmospheric temperatures. Monte Carlo permutation tests gave a probability value P = 0.08. Sampling unit 14 was the furthest from a shade gradient because it received an appreciable amount of sunlight compared to SU 12 and SU 13. This inference agrees with data in Appendix 7.

3.5.2 Sampling unit CCA for Zygoptera

Species -environment correlations for each axis was: AX1 = 0.99 and AX2 = 0.95. (Table 7; Fig. 27). Axis 1 was a pH, %Sh and RIVeg gradient, being negatively correlated with a water depth gradient. Axis 2 was a water and atmospheric temperature gradient, being negatively correlated with %Sh and SPPVeg gradient. Monte Carlo permutation tests gave a probability value P = 0.01. Sample unit 5 was unusual because it encompassed waterfall, dam and river ecological characteristics.

3.5.3 Sampling unit CCA for " all Odonata species"

Species-environment correlations for each axis was: AX1 = 0.99 and AX2 = 0.98 (Table 6; Fig. 28). Axis 1 was a pH; %Sh and RIVeg gradient while being negatively correlated with water depth and atmospheric temperatures. Axis 2 was a SPPVeg, water and atmospheric temperature gradient. To investigate whether the observed differences were accounted for by pure chance or not, the Monte Carlo permutation test with the first eigenvalue as test statistic was carried out. A probability value P = 0.01 shows that there were highly significant differences in the distribution patterns of Zygoptera and Anisoptera species among the 20 sampling units based mainly on the following environmental variable gradients: pH, percentage shade (%Sh), Vegetation plus degree of open water (RIVeg, SPPVeg, DRVeg), water/atmospheric temperatures (Wt/At) and water depth (Wd) in order or importance (Table 5).

This CCA ordination (Fig. 28) can be considered the most representative of the three species-environment correlation analyses because it summarizes the ecological patterns for the two suborders.

Table 5. Ordination results of CCA produced by running CANOCO using species data (Appendices 4, 5, 6) and the twelve environmental variables listed in section 2.3.1. Significant environmental variable gradients are shown in asterix

Inter-set correlations of environmental variables with axes						
Environmental variables	CCA(Anisoptera)		CCA(Zygoptera)		CCA(Anisoptera + Zygoptera)	
	Ax1	Ax2	Ax1	Ax2	Ax1	Ax2
Tu	0.05	-0.47	-0.48	0.505	-0.532	0.436
pH	0.525*	0.702*	0.846*	-0.263	0.871*	-0.091
At	0.044	-0.838*	-0.544	0.736*	-0.685*	0.628*
Wt	0.214	-0.763*	-0.307	0.800*	-0.476	0.741*
Wd	-0.462	-0.763*	-0.822*	0.428	-0.903*	-0.523
%Sh	0.051	0.860*	0.595*	-0.648*	0.722*	-0.523
RIVeg	0.643*	0.224	0.713*	0.370	0.688*	0.476
WFVeg	0.525*	0.022	0.189	0.403	0.193	0.457
DRVeg	-0.229	0.459	-0.417	0.318	-0.531	0.229
SPPVeg	-0.243	0.634*	-0.081	-0.699*	0.201	0.732*
SOSVeg	-0.058	0.288	0.382	-0.313	0.401	-0.266
OPPVeg	-0.189	0.176	-0.379	0.167	-0.378	0.085
Species-environment correlation coefficient	0.96	0.97	0.99	0.95	0.99	0.98

Tu = turbidity of water, pH = acidity of water, Wt/At = Water and ambient temperatures, Wd = water depth, %sh = percentage shade, RIVeg = River/vegetation, WFVeg = Waterfall/ vegetation, DRVeg = Dam/vegetation, SPPVeg = Semi-permanent pond/vegetation, SOSTVeg, Semi-open stream vegetation, OPPVeg = Open pond vegetation.

Table 6. *Ordination results of CCA and CA produced by running CANOCO. For CA, species data (Appendices 1,4, 5and 6) were used. For CCA, species data were related to the twelve environmental variables (section 2.3.1). Monte Carlo Permutation tests levels of significance are shown in asterix (*** = High significance).*

	Eigenvalues		Cumulative % variance for species data		Cumulative % variance for species-environment Relations		Monte Carlo test (First axis)
Analysis	λ_1	λ_2	Ax1	Ax2	Ax1	Ax2	
CCA Anisoptera	0.71	0.47	32.1	53.4	38	63.2	0.08**
CCA Zygoptera	0.55	0.31	35.8	55.4	41.5	64.1	0.01***
CCA (Both)	0.58	0.39	35.1	58.8	40.4	67.7	0.01***
CA Anisoptera	0.78	0.51	35.3	58.3			
CA Zygoptera	0.56	0.34	36	57.7			
CA (Both)	0.58	0.41	39.8	69.1			
CA (M)	0.21	0.11	43.1	65.1			

CA (M) = correspondence analysis for monthly species data (Appendix1)

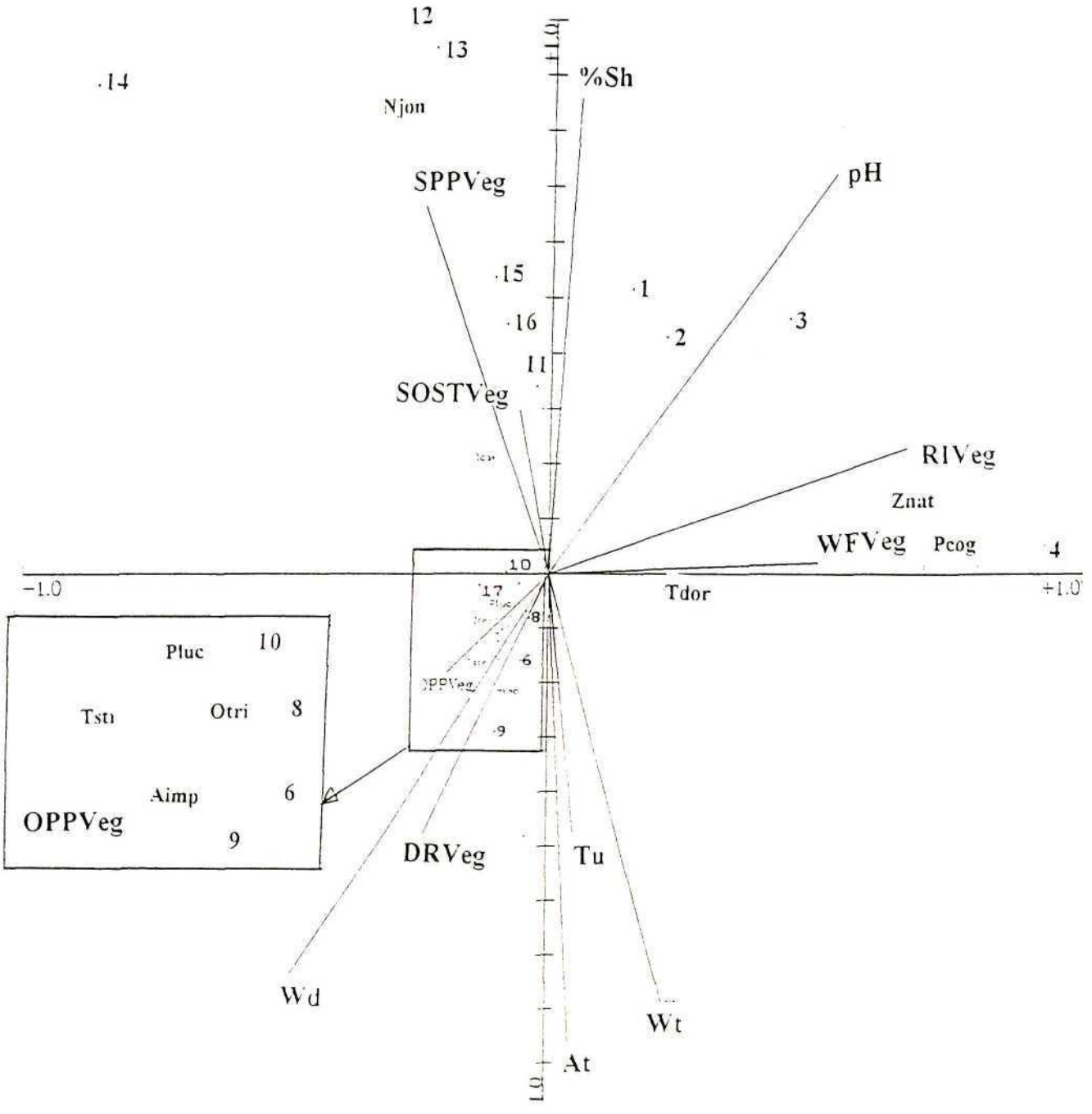


Fig. 26: Ordination diagram of canonical correspondence analysis (CCA), using data from the one-year sampling period. The diagram shows the distribution of Anisoptera species among the twenty sampling units (1-20 in bold type numbers) along twelve environmental variable gradients (oblique axes). Species names are abbreviated (see Table 1). The first axis $\lambda_1 = 0.710$ is horizontal and the second axis $\lambda_2 = 0.472$ is vertical. CANOCO was used.

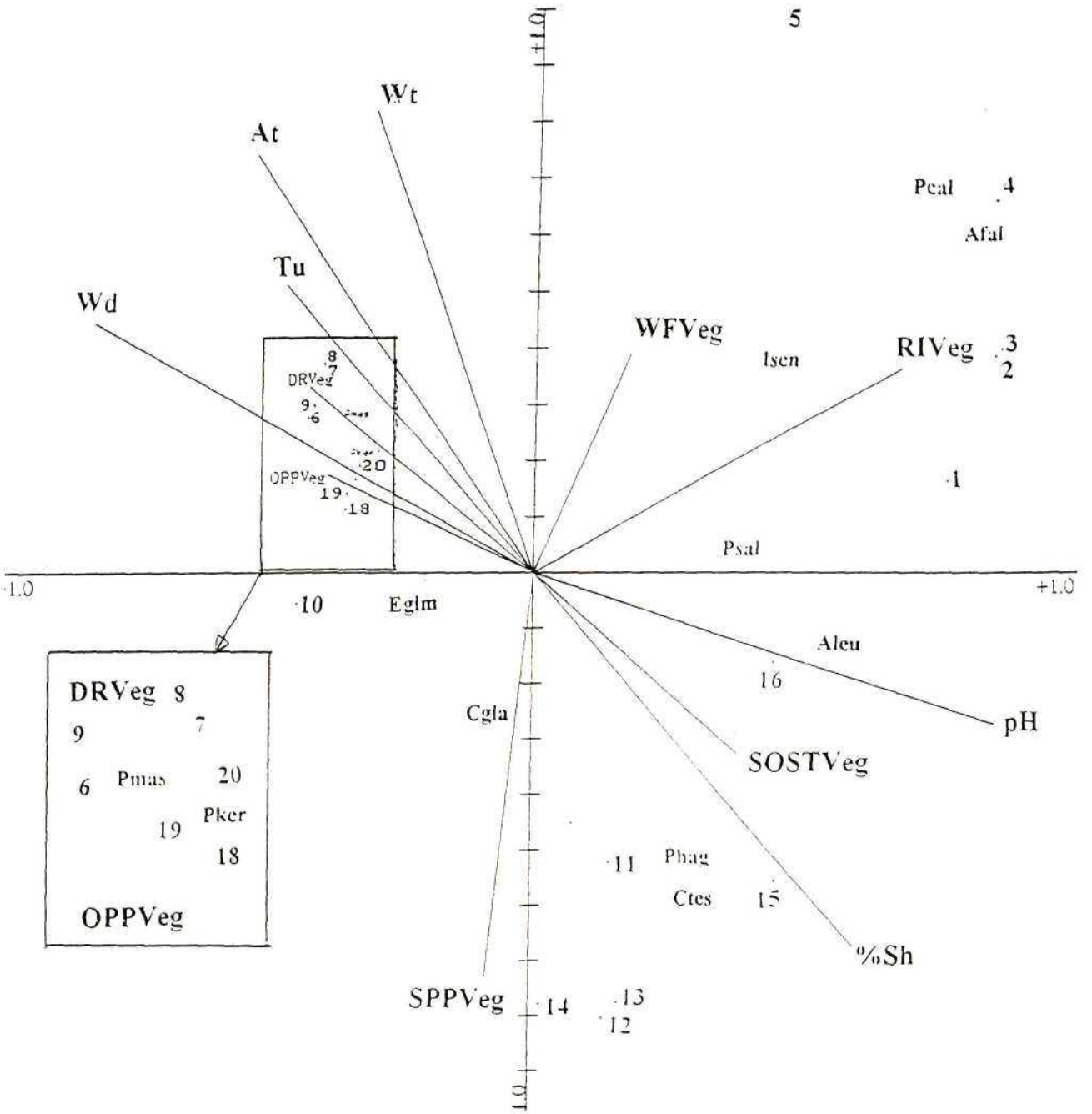


Fig. 27: Ordination diagram of canonical correspondence analysis (CCA), using data from the one-year sampling period. The diagram shows the distribution of Zygoptera species among the twenty sampling units (1-20 in bold type numbers) along twelve environmental variable gradients (oblique axes). Species names are abbreviated (see Table 1). The first axis $\lambda_1 = 0.554$ is horizontal and the second axis $\lambda_2 = 0.302$ is vertical.

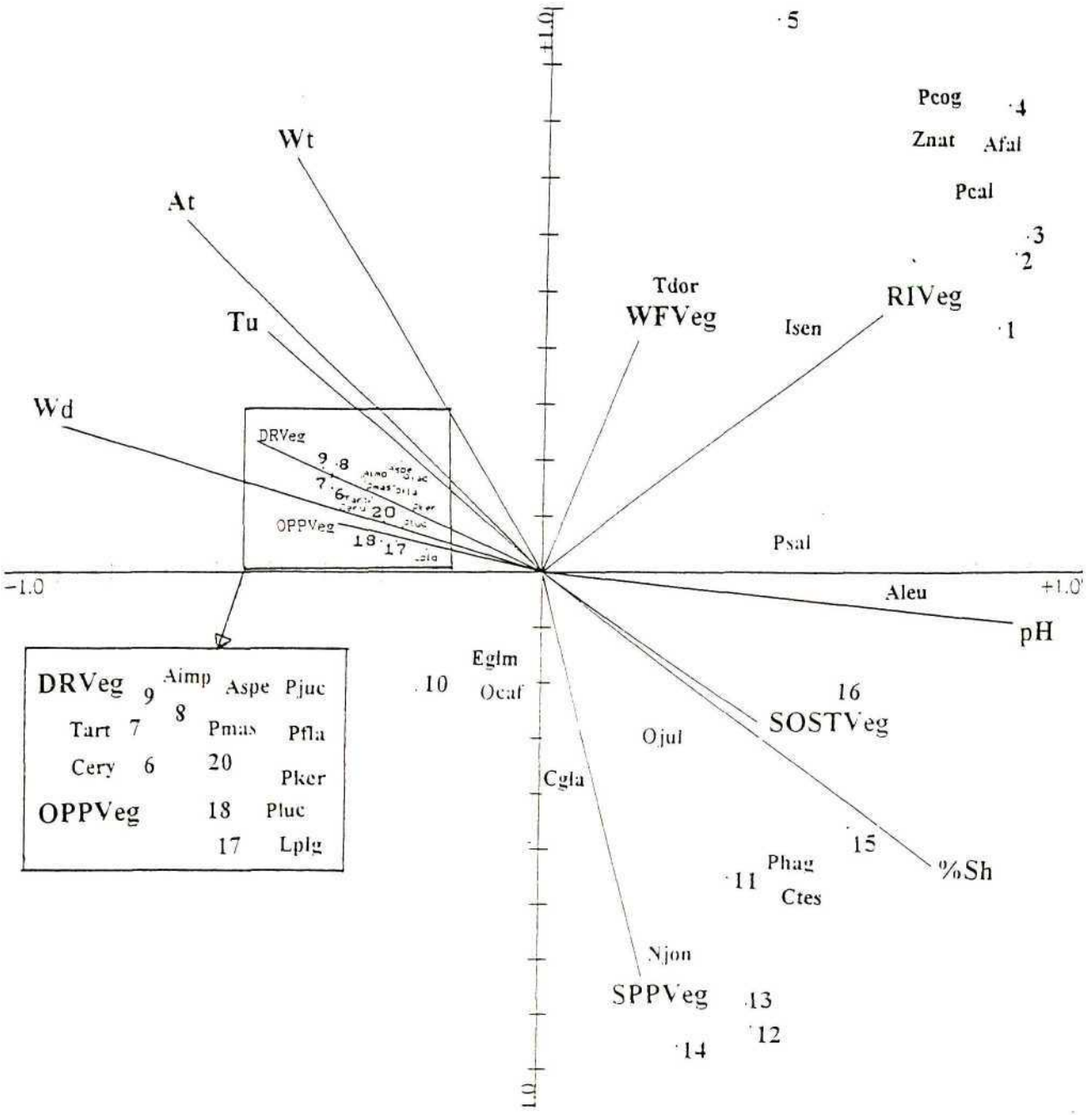


Fig. 28: Ordination diagram of canonical correspondence analysis (CCA), using data for the one-year sampling period. The diagram shows the distribution of 'all Odonata species' among the twenty sampling units (1-20 in bold type numbers) along twelve environmental variable gradients (oblique axes). Species names are abbreviated (see Table 1). The first axis λ_2 = 0.582 is horizontal and the second axis λ_2 = 0.394 is vertical. CANOCO was used.

3.6 Survey of public awareness (visitors to the botanical gardens)

A copy of the questionnaire used is given in Appendix 10. Media choice for learning more about dragonflies decreased as follows: Posters (35 %), Leaflets (26 %), Photographs (21 %), Guides (16 %) and Slides (2 %) (Fig. 29). Individual responses fell into three distinct classes: Awareness, Ignorant or Not Interested (Fig. 30), with age groups 1-12, 13-19, 20-35, and 61+ responding at varying percentage levels of all three categories. Also, three classes of responses: Committed, Conditionally Committed and those not committed (Fig. 31) were obtained from respondents.

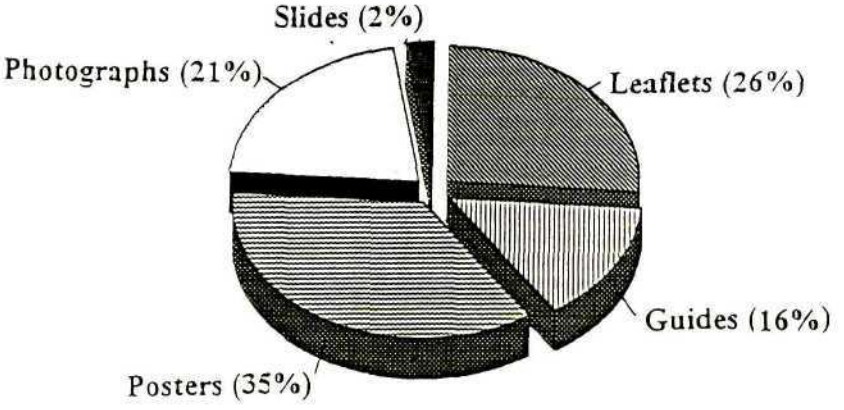


Fig. 29: Percentage preference by visitors to the botanical gardens with regard to medium that they would prefer to learn more about dragonflies

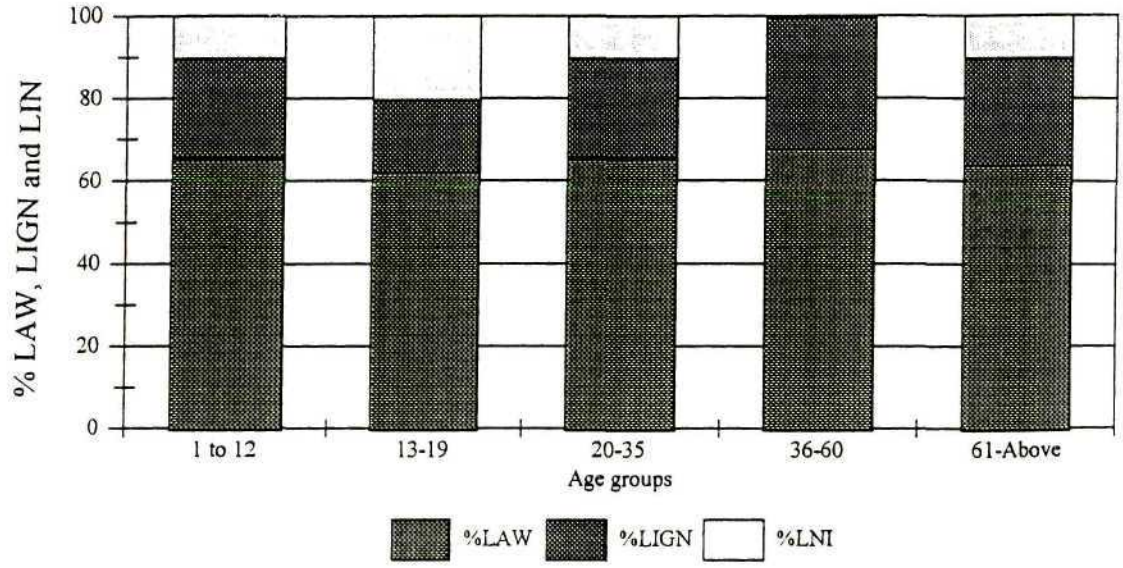


Fig. 30: Percentage level of Awareness (LAW), Ignorance (LIGN) and Not Interested (LNI) among the five age groups of visitors interviewed at the botanical gardens.

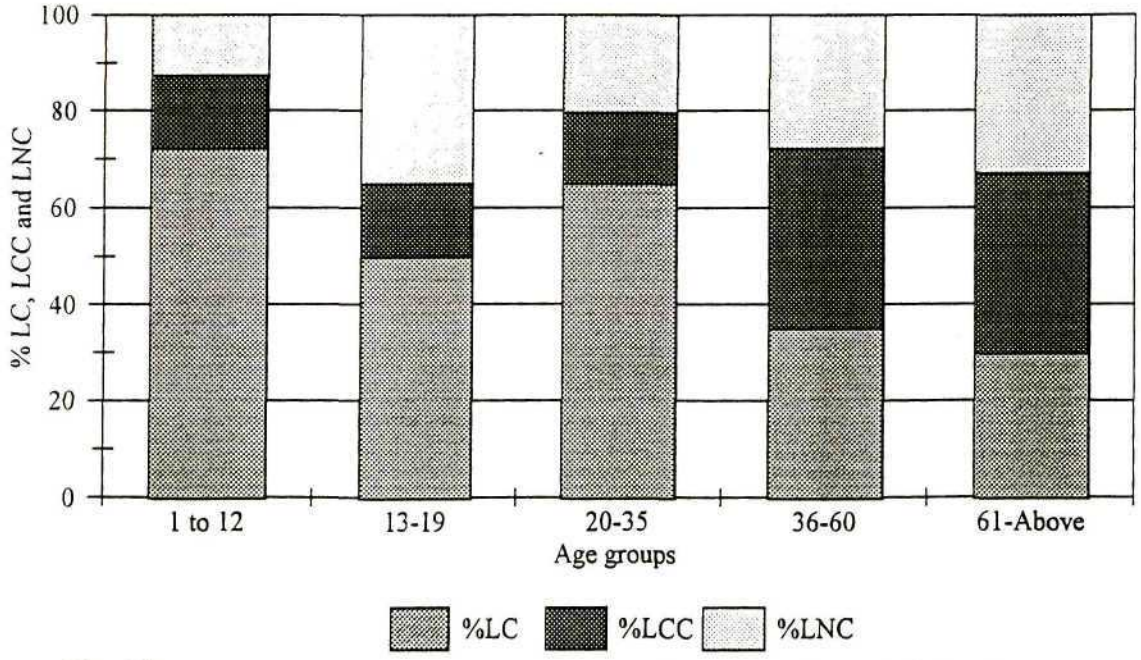


Fig. 31: Percentage level of: Commitment (LC), Conditional Commitment (LCC) and non Committed among the five age groups of visitors interviewed at the botanical gardens

CHAPTER 4

DISCUSSION

4.1 Species richness

4.1.1 At the whole site

The species cumulative curve (Fig. 8) shows that some species were found in all months of the year e.g *E. glaucum, L. plagiatus, O. julia, C. erythraea* and *P. salisburyense*. For the whole sampling period, 35 species (20 Anisoptera and 15 Zygoptera) were recorded, accounting for 22% of the South African odonatan species, and about 30% of KwaZulu-Natal's 117 recorded species. The Pietermaritzburg Botanical Gardens, located at 650m.a.s.l, and close to the foot of the Drakensberg, is much richer in odonatan species than the whole of the high Drakensberg (above 1500m.a.s.l) with its 22 recorded species (Samways and Whiteley 1997). The gardens' dragonfly fauna is nearly as much as the British odonatan fauna, with its 38 species, and, as such, offers much odonatan variety for potential visitors.

An earlier study, exclusively of the pond impoundment on the Dorpspruit (a small river) river at the botanical gardens, recorded 26 species (Steytler and Samways 1994). The increased species richness in this study was partly due to the sampling period being longer, and being over a whole year. Also, the main pond, established in 1989, was now much richer in vegetation. Moreover, the Odonata assemblage is relatively labile, with a spectrum of characteristic residual species and a satellite group of irregulars (Steytler 1994). Figs 8, 9, 10 and 25 show that November to April were species-rich months. These months were characterized by the highest ambient and water temperatures associated with summer. But also, high light intensity, high water levels, abundant vegetation and high pH were present. These conditions are suitable for larval development, adult dispersal, aggregation and oviposition. The months of June to October were species-poor months, and were characterized by cold winter conditions, with low water/ambient temperatures, low water levels and low pH all of which do not favour oviposition, dispersal or aggregation in adults, nor distribution and development of larvae (Corbet 1962, 1999; Miller 1987).

Low water levels may act alone or synergistically with other factors in causing population fragmentation in Odonata during this dry time of the year (Moore 1997). Odonata species probably survived the cold winter as larvae, or less commonly as eggs e.g Lestidae. Larvae of *P.flavescens* died in Japan below 4^{0}C (Nagase 1983; Arai 1991; Corbet 1999).

4.1.2 Individual biotope species richness

The increased species richness in SUs 5 (waterfall), 6-9 (dam), 10, 17-20 (open ponds) (Fig.15) was correlated with a number of environmental factors, particularly increased amount of sunshine with fewer trees. Low abundance and high species richness in SUs 5 could be attributed to the compositional and structural complexity of this sampling unit, part of which was a waterfall with a rocky embankment of exposed rocks. These rocks served as basking sites for many dragonfly species from adjacent water bodies. SU10 had the highest number of individuals but lower species richness due mainly to highly dominant species such as *Enallagma glaucum*. SUs 6-9, 17-20 had a high species turnover, probably because of occasional, deliberate clearing of weeds at these sites and influx of individuals from adjacent sites. SU9 also had high species richness due to its wetland/marshland characteristics. SUs 2-4 (Forested river) equally recorded a high number of lotic species, while shaded pond/stream SUs (11-16), including the open section of the river (SU1) recorded a lower number of species. Clearly, biotope heterogeneity plays a major role in promoting local species richness.

4.2 Sampling unit classification and ordination

The Multivariate statistics were able to classify species sampling units into six, five and four-ecologically meaningful groupings for Anisoptera, Zygoptera and 'all Odonata species' data respectively. MDS stress levels of (0.06, 0.06 and 0.05 respectively) showed that these groupings were quite reliable. SU1 represented the least number of Odonata species, while for Anisoptera species cluster, SU5 (Fig.16) was midway between pond and river. This SU was an outlier in terms of Anisoptera species assemblage composition, because of its unique ecological characteristics.

For Zygoptera species clustering and ordination (Figs 17, 20), SU5 shows more similarity to SU2, SU3 and SU4 at 72% level of similarity. The four distinct sampling unit groupings obtained (at 62% level of similarity when "all Odonata species"clusters were analyzed) were: SU1 (open section of forested river), SU2-SU5 (forested river), SU11-SU16 (shaded semi-permanent pond/stream), and SU6-SU10, SU17-SU20 (open permanent ponds/dam). The MDS ordination plot generated from these clusters was at a highly reliable stress level of 0.05.

Table 4 shows discriminator species that were responsible for sampling unit groupings. Group six, with a size of 15 sampling units, had the following discriminator species obtained at an average similarity level of 59.7%: *C. glabrum, O. julia, E. glaucum, L. plagiatus, P. salisburyense,* and *P. kersteni*. These results clearly show that the Odonata assemblage is highly influenced by habitat characteristics and the sampling units could be classified on the basis of their Odonata assemblage. However, there were a number of biotope-tolerant species, from both suborders, that were highly dispersive, lotic and/or lentic species e.g. *O. julia, P. flavescens, P. kersteni* and *P. salisburyense.* From the sampling unit groupings, a new sampling unit could be assigned to one of the four habitat types on the basis of overall species composition, richness and diversity (Appendix 4). Habitat classification based on Odonata species assemblage composition provides the conservationist with information on species to be expected under a given set of habitat conditions. However, the main factors affecting the Odonata assemblage composition must first be established, as below.

4.3 Sampling unit ordination

Odonata/sampling units ordination using correspondence analyses were similar to those obtained using MDS. They showed a clear separation of sampling units according to ecological and assemblage groupings for Anisoptera, Zygoptera and 'all Odonata species'. The Anisoptera species biplot showed a tendency for pond sampling units to cluster together at the centre, due to similar habitat conditions (Fig.22). The vertical variation across axis 2 was attributable to heavily shaded pond/stream sampling units and suggested that the shade variable was responsible for this. Consequently, SU2 shared more habitat characteristics with SU11-SU14 than with SU2-SU5.

For the Zygoptera and 'all Odonata species' biplots, (Figs 23, 24), pond sampling units (SU6-SU10,SU17-SU20) were quite distinct from river sampling units (SU1- SU4,) and shady pond/stream (SU11-SU14, SU15-SU16) characteristics.

4.4 Significance of environmental variables

4.4.1 Biotope specialization versus biotope tolerance

Biotope preference can be seen as a spectrum of species-environment relations ranging from restriction to one biotope on the one hand and tolerance of many biotopes on the other. However, the classification of species on this basis is highly subjective, especially with a usually highly dynamic dragonfly assemblage. Steytler and Samways (1994) found that the biotope requirements of a biotope specialist is multidimensional for sun/shade,flow/pond and vegetation among other factors. Similarly, in this study, some Anisoptera and Zygoptera species showed distinct characteristics of specialization as shown in Table 7.

P. flavescens has been documented as a well-known global migrant (Corbet 1962) but has a specialized breeding requirement for shallow, warm, temporary pools (Samways and Caldwell 1989). In the case of *P. flavescens*, enhanced mobility adds a further consideration when defining a species as either tolerant or specialist, because at the fine scale of measurement used in this study, this species was classed as biotope tolerant.

Inferences on biotope specificity can only come from additional studies on larval biotope requirements. However, Hawking and New (1999) found that there was considerable concurrence in distributional patterns between adults and larvae so that either stage alone may provide data of value in faunal assessments. Nevertheless, analyses here indicated that as a group, the Zygoptera species show more stenotopic tendencies than the Anisoptera species. Clark (1992) and Samways (1994) suggest that the higher degree of biotope specificity among Zygoptera species is probably related to lower powers of dispersal. It is important to note that the biotope requirements of any one Odonata species may be temporarily or spatially defined (Steytler and Samways 1994). The same species in a different geographical area or in a different species assemblage may show a slight change in biotope preference.

Table 7. Anisoptera and Zygoptera species classified as biotope specialist and biotope tolerant.

Suborder	Biotope specialist	Biotope tolerant
Anisoptera	*T. arteriosa, C. erythraea, T. stictica, N. farinosa, P. lucia*	*O. julia, P. flavescens, A. imperator*
Zygoptera	*P. massaicum, C. tessellatus, P. hageni, A. leucosticta, A. falcifera, E. elongatum*	*P. kersteni, P. salisburyense, C. glabrum, L. plagiatus*

4.5 Species-environment relationships

Anisoptera and Zygoptera have different species-environment relations. Analyzing the two suborders separately resulted in more informative CCA solutions. Results showed a high amount of variation in the Anisoptera data as seen by the high first axis eigenvalues (Table 6). Also, Zygoptera species showed a higher total variation of 64.1%. Using the three ordination diagrams (Figs 26-28), Odonata species recorded in all 20 sampling units during the one-year study period could be classified according to their location in a sampling unit versus environmental variable space in an ordination biplot.

Species could be influenced positively, intermediate/neutrally or not at all by significant environmental variable gradients (see species classification based on these influences for this study in Table 8). This inference agrees with Ter Braak (1986) who specifies that the length of an eigenvector (arrow denoting an environmental variable gradient in an ordination diagram) is equal to the rate of change in weighted average as inferred from the biplot, and is therefore a measure of how much the species distribution differs along that environmental variable gradient. Important environmental variables therefore tend to be represented by longer arrows than less important ones. According to Ter Braak (1986), when an eigenvector is extended in both directions, sample unit species located at or around the head of the vector (positive end) in an ordination diagram are positively influenced above average by the environmental variable denoted by that vector. On the other hand, sampling units/species located at or around the negative end of the same vector in the opposite quadrant of the biplot are influenced negatively or not at all. It is important to note that the Odonata species that were classed as often appearing in the intermediate category i.e species occurring in the middle of many environmental gradients were mostly biotope tolerant.

4.5.1 Multivariate analyses of Anisoptera species data

Sampling unit 14 was farther away from the shade gradient because it received some sunlight. However, it showed a similar species assemblage with the other sampling units in this habitat group (Fig.24). The lower variation in the scatter of species points indicated that the remaining species had similar species-environment relationships.

Table 8 : Odonata species that occurred in sampling units with positive, intermediate and Negative influence of significant environmental variable gradients of pH, percentage shade (% Sh), water depth (Wd), water and ambient temperatures (Wt/At), and vegetation (river vegetation (RIVeg), semi-permanent pond vegetation (SPPVeg) and dam vegetation (DRVeg)).

pH gradient		
Positive	Intermediate (neutral)	Negative/none
P. salisburyense, P. kersteni	*I. senegalensis, O. julia,*	*A. imperator, A. speratus*
P. cognatus, Z. natalensis	*P. hageni, C. tessellatus*	*C. erythraea, P. lucia,*
A. leucosticta, P. caligata	*C. glabrum, N. jonesi*	*N. farinosa, T. arteriosa*
%Sh gradient		
Positive	Intermediate/ neutral	Negative/none
P. hageni, C. tessellatus	*O. julia, O.caffrum,*	*A. speratus, A. imperator*
N. jonesi, A. leucosticta	*C. glabrum*	*P. flavesens, T. arteriosa,*
		C. erythraea, P. lucia
Wt/At gradient		
Positive	Intermediate/neutral	Negative/none
A. imperator, A. speratus	*O. caffrum, I. senegalensis*	*P. hageni, C. tessellatus*
C. erythraea, T. stictica,	*P. kersteni, P. salisburyense*	*N. jonesi*
L. plagiatus, P. massaicum	*T. dorsalis*	
Wd gradient		
Positive	Intermediate/neutral	Negative/none
C. erythraea, T. arteriosa	*E. glaucum, C. glabrum*	*A. leucosticta, C. tessellatus*
P. massaicum,	*O. julia, P. kersteni*	*Z. natalensis, A. falcifera*
	P. salisburyense	*P. caligata*
SPPVeg gradient		
Positive	Intermediate/neutral	Negative/none
N. jonesi, P. hageni,	*O. julia, P. kersteni, C.*	*P. cognatus, Z. natalensis*
C. tessellatus, A. leucosticta	*glabrum*	
	P. salisburyense	
RIVeg gradient		
Positive	Intermediate/neutral	Negative/none
A. falcifera, Z. natalensis	*L. plagiatus, C. glabrum*	*T. stictica, A. imperator, P.*
P. cognatus, P. caligata	*E. glaucum, O. julia*	*lucia, C. erythraea*
DRVeg gradient		
Positive	Intermediate/neutral	Negative/none
A. speratus, A. imperator	*E. glaucum, O. caffrum*	*A. leucosticta, P. hageni*
T. arteriosa, C. erythraea	*C. glabrum*	*N. jonesi*
P. flavescens, N. farinosa		

See CCA ordination diagrams (Figs 26, 27, 28).

For these Anisoptera species, the CCA ordination of species and sampling units was consistent with the raw data in Appendix 4 and was satisfactory for relating the environmental variables.

4.5.2 Environmental variables

About 63.2% of the total variance was accounted for by the environmental variables. The remaining 36.8% being due to noise in the data (Gauch 1982). PH, percentage shade, water and ambient temperatures, vegetation and water depth variables accounted for most of the variation in the CCA solution (Fig.26) as they were strongly correlated with axes 1 and 2 (Table 5). These environmental variables were the most important of the measured variables for adult Anisoptera biotope suitability.

Most species e.g. *C. erythraea, T. arteriosa, N. farinosa* and *Anax* species occurred in sunny sampling units where the ambient and water temperatures were high, hence meeting their heliophilic requirements. Such conditions were characteristic of sunlit ponds (SU6-10,SU17-SU20). Very few species occurred at the other extreme of this biotope gradient, where conditions were partly shaded. Cool water temperatures in these sampling units were typical of the shaded ponds, stream and river species: *N. jonesi, P. cognatus* and *Z. natalensis*. Clark (1992), Stewart (1993), Steytler and Samways (1994) have shown that distinct lotic and lentic species are identifiable. The majority of Anisoptera species here were lentic species which preferred slow moving pools or impoundments. There was a strong positive correlation between river/vegetation, waterfall/vegetation and *P. cognatus*. This species had been recognized as a lotic species by Steytler and Samways (1994). *Z. natalensis* and *T. dorsalis* were also lotic species recorded in this study even though the latter species was spotted in ponds as well (Fig. 26; Table 5). *O. julia, P. flavescens, T. dorsalis* were biotope tolerant. *Orthetrum julia falsum* and the two commonest *Anax* species recorded in this study were also identified by Steytler and Samways (1994) as typically biotope tolerant.

4.5.3 Multivariate analyses of Zygoptera species data

About 64.1% of total variation in Zygoptera species data was accounted for by environmental variables. This suggests a high species-environment relationship among the Zygoptera.

The CCA solution of species and sample units (Fig. 27) was consistent with the species data and was satisfactory for relating to the environmental variables.

4.5.4 Environmental variables

The environmental variables in conjunction with the species points accounted for the variation in the Zygoptera data. Some of this variation may be accounted for by the third axis. Relating these axes to the environmental variables (Table 5) showed that most of the variation was accounted for by the effects of important environmental variables such as pH, percentage shade, water and ambient temperatures, water depth, and vegetation. These same environmental variables account for most of the variation in the Anisoptera species data (Table 5). This suggests that most Zygoptera and Anisoptera species were influenced by the same variable gradients. When both data were subjected to Monte Carlo permutation test with first axes eigenvalues each as test statistic, a probability value P = 0.01 was obtained for Zygoptera and P = 0.08 for Anisoptera. These values confirmed that the distribution patterns for the two suborders among the 20 sampling units was purely based on the influence of significant environmental variables identified in this study and not on chance.

This is not to say that they showed the same type or degree of response to these variables or that other variables are not important at a more refined level. The biplots of species and environmental variables show, by the relative positions of the arrows, that the significant environmental variables mentioned above did not have the same effect on the Zygoptera species (Fig.27) as they did for the Anisoptera species (Fig.26). The results of the ordination biplots support the identification of biotope types based on species assemblage composition. With the knowledge of what species to expect under a given set of biotope conditions, changes in species composition may reflect changes in biotope structure, including quality.

4.6 Environmental variables and biotope tolerance of species

Percentage shade, pH, water and ambient temperatures, water depth and vegetation were very important environmental variables for both Anisoptera and Zygoptera species.

Zygoptera species occurred at both extremes of these environmental variable gradients and reflected greater ecological diversity than Anisoptera species.

Except for *N. jonesi* and *O. julia,* Anisoptera species occurred in sampling units with full sunlight much marginal vegetation and minimal water flow. Open-pond sampling units were particularly rich in Anisoptera species.

Oviposition is the culmination of habitat selection in Odonata (Corbet 1999). It can take place endophytically or exophytically (Corbet 1962). Gonzalez- Soriano (1987) has included a third category, that of epiphytic oviposition, which is the attachment of eggs to the surface of plants. The classification above is not informative enough for present needs (Corbet 1999). Dragonflies show wide intraspecific variation in oviposition mode which is often facultative. It is necessary to allow for variation in mode of oviposition for two reasons: first, a single observation of oviposition mode may not be representative and second, when the choice of oviposition mode is facultative, it can be used to infer factors that are determining the several modes and thus to infer their selective action on the oviposition process (Corbet 1999).

Many Zygoptera and Anisoptera species were observed ovipositing in tandem at sampling sites, especially at the open pond and dam from November to April. Oviposition behaviour was observed in *Anax imperator* at a marsh close to the dam. Not all sightings of adult Odonata at a particular water body are indications of successful breeding (Steytler and Samways 1994). However, since the distribution of most Zygoptera species here were localized and abundant, it is likely that successful breeding was occurring. Watson *et al.* (1982) found that some species which bred in isolated and restricted, permanent biotopes remained close to their emergence sites. Biotope selection is governed to a large extent by vegetation characteristics and macrophytes play a major role in determining habitat structure because dragonflies are closely associated with them in every ontogenic stage (Corbet 1999).

Corbet (1999) has listed ways in which the occurrence of dragonflies appears to be linked (or not linked) to vegetation. These correlations are consistent with the hypothesis that the structure and appearance 'architecture' of plants or plant communities rather than individual plant species are likely to serve as cues for biotope and habitat recognition.

Most Zygoptera species occurred in a broad range of vegetation conditions such as the indigenous, characteristically highly shaded stream/pond biotope to fully sunlit sampling sites with large amounts of vegetation. Emergent macrophytes along the river, ponds stream and dam constituted a very important variable relative to vegetation type for most Odonata and served as perching, foraging or sites for shelter from predators.

Osborn and Samways (1996) have suggested that 'assembly rules' in Odonata may be governed more by factors external to the taxon than interspecific competition. Sunlight/shade regimes, and other factors, are important in Odonata biotope selection, with adults showing a preference for certain sunlight/shade regimes. This has been documented by Clark and Samways (1996); Stewart and Samways (1998); Steytler and Samways (1994); McGeoch and Samways (1991). Water/ambient temperatures and sunlight/shade were interrelated. Steytler and Samways (1994), found that a river, stream, or pond, with a dense riparian strip that almost totally shades the water surface, will retard the warming up of water. This explains the cause for the usually low temperature records made in shade sampling units. The association with water and ambient temperatures was also a reflection of the importance of sunlight. The amount of sunlight also affected plant growth.

Direct effects of pH are difficult to infer rigorously from field studies, with possible correlations between odonate distribution and pH leading to different conclusions (Hämäläinen and Huttunen 1990). Some odonatan species can tolerate wide changes in pH, and distribution patterns correlated with ambient pH in the field are often determined by other factors. However, pH may vary seasonally, with Zygoptera species being more tolerant to high pH than Anisoptera species (Corbet 1999). Low pH recorded during winter months may have affected larval survival and distribution.

When interpreting the ecological significance of depth distribution among Odonata larvae in lentic waters, one must bear in mind the correlates of increased levels of water (Thorp and Diggins 1982) which include less structural complexity, substrate heterogeneity, food, and fluctuation of temperature. In lentic waters, Odonata larvae (especially Anisoptera) are found predominantly in shallow water less than a metre deep near the edge. Samways *et al.* (1996) have noted that over 98% of macroinvertebrate individuals in 21 species and 14 families (including

Odonata) occurred in water 1m or less in depth, and associated with the water plant *Elodea* species which did not occur much beyond this depth. Water levels of the range of 17.5-21.3cm deep were recorded here during the summer season (Appendix 7). In lotic waters, water movements and consequently substrate particles size are likely to determine the depth larvae occupy (Corbet 1999). Water levels in lotic biotopes ranged from 3-6.5cm deep during summer. Lowered water levels also experienced during winter months may also have affected larval and/or adult Odonata, acting alone or in synergy with other factors to cause species population drops or fragmentation (Moore 1997).

4.6.1 Identification of biotope types

The biotope of a species which varies with space and time is represented by different levels of scale, complexity and heterogeneity (Corbet 1999).

A useful scheme has been outlined by Schmidt (1985) to identify biotopes by a representative Spectrum of Odonata (RSO).

In this study, the recognition of distinct biotope types and their characteristic Odonata species assemblages along with the investigation of species distributions along important environmental variable gradients allowed for the identification of a variety of Odonata biotopes (Table 9). The biotope types identified for Anisoptera and Zygoptera were the same. These assemblages had many species in common and a few 'indicator' species whose presence or absence differed between the assemblages. *P. caligata* was an indicator for the lotic biotope (forested river) as it occurred only in this biotope type. *C. tessellatus* and *A. leucosticta* occurred exclusively in the 'forested/shady pond/stream biotope'. The lentic biotope was characterized by species such as *C. erythraea, T. stictica* and *P. massaicum*. These species occurred exclusively at the open ponds/dam.

The biotope types were defined using the important environmental variables: pH, percentage shade, water and atmospheric temperatures, water depth and vegetation. An important variable affecting dissolved oxygen in aquatic habitats is water movement. Not only do species segregate broadly with respect to lotic and lentic habitats, but within a water course, assemblages of species segregate according to speed of flow (Corbet 1999).

Table 9. Biotope types with important environmental variables and species assemblages described. Species occurring exclusively in a biotope type are denoted by an asterisk. Environmental variables and species names are abbreviated. See Table 1 for full species names. Not all species recorded are included in this table. CCA in CANOCO was used.

Biotope type	Environmental Variables	Anisoptera	Zygoptera
Waterfall	No %Sh High WFVeg High Wt/At High Flow Basic pH Low Wd	Ojul, Tdor*, Tart, Nfar,	Psal, Pker, Isen* Afal*, Cgla
Forested river section	Med %Sh High RIVeg High Wt/At High Flow Basic pH Med Wd	Ojul, Znat*, Pcog*	Pcal*, Psal, Afal, Eelo*, Eglm,
Open ponds/dam	Low % Sh High DRVeg High Wt/At Low Flow Acidic pH High Wd	Nfar, Tart, Cery* Tsti*, Aimp, Aspe Ojul	Cgla, Lplg,Isen*, Pmas*, Eglm, Psal, Pker
Shaded pond/stream	High % Sh High SPPVeg Low Wt/At Low flow Neutral pH Low Wd	Ojul, Njon*	Cgla, Lplg, Phag* Ctes*, Aleu*, Pker, Psal

Water movement determines other physical conditions besides dissolved oxygen, notably substrate. Clark (1992) demonstrated that flow rate was also among other environmental variables that could be used in assigning a sample unit to a biotope type. Flow rate was not identified here as an important environmental variable, probably because of the gross quantification of this variable.

The six habitat types chosen a priori gave rise to four biotope groupings classified on the basis of Odonata assemblage composition. The results obtained by using the two multivariate methods (PRIMER and CANOCO) were quite similar (with four biotope groupings each) except that sample unit five (waterfall) was recognized as a distinct biotope when CCA in CANOCO was run with environmental variables, instead of sample unit one (open section of forested river) when a cluster analysis (followed by MDS ordination) of species/sampling units was run using PRIMER. The waterfall biotope was distinct in terms of its dragonfly assemblage, probably because it was centrally located between the dam and the river, resulting in the interaction of many ecological factors, in addition to the fast water flow, which attracted *Z. natalensis*. This ecological variety in one spot also contributed to high species richness in this biotope at this spatial scale. The river biotope, was also distinctive, the dam, merged with other open ponds, formed the third biotope group in terms of dragonfly assemblage. The fourth group was formed by merging the semi- permanent, shaded pond with its stream outlet. Table 9 may be used as a baseline for future studies in the botanical gardens or elsewhere.

4.7 Design of the trail

4.7.1 Usefulness of the scientific results

Spatially, species showed variable responses to significant environmental variables such as pH, percentage shade, vegetation (both structural and compositional), ambient temperature, water temperature and water depth. Results from the classification and ordination of sampling units showed that the 20 sampling units were highly variable in species richness and diversity. Four dragonfly biotope types resulted from six habitat classes selected before the study.

These biotopes were: 'waterfall', 'forested river', 'shaded semi-permanent pond/stream' and 'open ponds/dam'. The 'open ponds/dam' biotope had the highest number of species and individuals. Species assemblage composition across the four biotopes was made up of both rare and abundant, and of both localized and widespread species. Many of these biotopes showed a marked degree of spatial isolation one from another, and they were highly heterogenous. Danielson (1991) and Corbet (1999) have pointed out that biotope heterogeneity influences interaction between species. Webb (1989) also states that the interaction between patches and their matrices influences species abundance. Certainly, it appears here that the complex variety of abiotic and biotic conditions between the different water bodies and their surroundings, in turn, created a variety of conditions for a wide range of dragonfly species. In a study on butterflies in the same botanical gardens, Wood and Samways (1991) showed that the various landscape elements such as lawns and blocks of trees can alter butterfly flight paths. If this is the case with dragonflies, which is not known at present, it would seem important to encourage the establishment of smaller ornamental ponds and other water bodies to ensure dragonfly biotope connectivity. This would also fall in line with designing a compact, connected dragonfly trail for visitors to the botanical gardens.

A clear starting point in design of the trail, is that four of the dragonfly hotspots on the trail should coincide with the four heterogenous scientifically determined biotopes. However, these four are insufficient in terms of number of physical linkages needed for having a complete trail around the botanical gardens. Besides, there were other considerations: 1) the need for rest points for people, 2) information on pond design for those people who may wish to create their own pond, 3) length of trail (long enough to be enjoyable but not too long as to cause weariness), and 4) break-off points for those who do not want to follow through the whole trail. Bearing these points in mind, it was crucial to supplement the scientific findings with practical realities on trail design. In consultation with experts in this field at the botanical gardens (Brian Tarr and John Roff), it was decided to add three more hotspots. Two of these were duplicate hotspot (the open pond at the gate and the one closer to the dam), which were rich in species, and were crucial physical linkages to make the trail easy for the public to follow and more complete in terms of resting or stopping-off points. The third hotspot was added to illustrate how a dragonfly

pond might be made and/or maintained. Twenty-five species (12 Zygoptera and 13 Anisoptera), out of thirty-five species in all, were finally chosen for inclusion in the preliminary dragonfly trail brochure which eventually will be modified by the National Botanical Institute in accordance with their standards for presentation. The remaining ten species (see species with asterisk in Table 10), were excluded arbitrarily, based on their low abundance ($n<10$) at the research site during the whole sampling period. These species were too rare and unlikely to be seen by a casual visitor to the botanical gardens. Moreover, a casual visitor would better appreciate and recognize rare dragonfly species only after knowing the more abundant and widespread ones. Also, 25 species were considered quite sufficient a number for the casual observer.

The study clearly shows that it was possible to find some dragonfly species and individuals throughout the year, especially certain damselflies. In winter, the only species on the wing were *P. salisburyense*, *P. kersteni*, *L. plagiatus*, *E. glaucum*, *C. glabrum*, *O. julia*, and *C. erythraea*. This suggests that the trail need not be disbanded during the winter. Rather, visitors curious to see dragonflies can easily be directed specifically to these species (especially as they are among the most biotope tolerant). For regular visitors, this would enable them to acquaint themselves with typical dragonfly biotopes before the summer months come with greater abundance and species richness. Periods of the day during which dragonflies can be watched are equally important, as it is generally not easy to see dragonflies very early in the morning or on a wet day. Whether in winter or summer, the dragonfly species here are all most easily seen just before or after noon on warm, sunny days. Although the scientific work underpinning the design of this dragonfly trail was illuminating biologically, there is some doubt whether, in designing trails at future locations, it is necessary to undertake such an exhaustive study. Four one-monthly sampling occasions were maintained throughout the entire sampling period (i.e 48 sampling occasions per year). When a species cumulative curve is drawn, starting, say, the beginning of December, the asymptote is reached (excluding the rare and casual visitors) after the 4 sampling occasions (at the end of December), when 25 most abundant dragonfly species (13 Anisoptera and 12 Zygoptera) were accounted for (Fig. 32). This strongly suggests that when designing future trails a few visits will suffice in determining the Odonata species richness of the area. However, caution is required as certain crepuscular and vagile species could be missed.

Table 10. Species assemblage on the dragonfly trail

Scientific name	Common name	Habitat preference
Enallagma glaucum	Common African Blue Damselfly	P
Lestes plagiatus	Highland Emerald Damselfly	P
Orthetrum julia	Julia's Skimmer	I
Trithemis dorsalis	Upland Spectrum-blue Dropwing	P/S
Palpopleura lucia	St Lucia Widow	P
*Palpopleura jucunda**	Lesser Widow	P
Crocothermis erythraea	Scarlet Dragonfly	P
Trithemis arteriosa	Red-veined Dropwing	P
Pseudagrion kersteni	Kersten's Sprite	S/P
Pseudagrion salisburyense	Salisbury'Sprite	S/P
Chlorolestes tessellatus	Forest Sylph	S
Allocnemis leucosticta	Goldtail	S
Ceriagrion glabrum	Orange Pond Damselfly	P
*Orthetrum caffrum**	Mountain Marsh Skimmer	I
Notiothermis jonesi	Tiny Forest Watcher	P
*Phaon iridipennis**	Glistening Demoiselle	I
Anax imperator	Emperor	P
Nesciothemis farinosa	Ashen Black-tailed Skimmer	P
Paragomphus cognatus	Brook Club-tail	S
Pantala flavescens	Globe Skimmer	I
Anax speratus	Orange Emperor	P
Trithemis stictica	Jaunty Dropwing	P
Pseudagrion massaicum	Massai Sprite	P
Zygonyx natalensis	Cascader	S
Agriocnemis falcifera	White-Masked Whip	S
*Anax tristis**	Magnificent Emperor	I

*Philonomon luminans**	Barbet	P
*Orthetrum trinacrium**	Marsh Skimmer	I
Ischnura senegalensis	Marsh Blue-tailed Damselfly	P/S
Pseudagrion hageni	Painted Sprite	P/S
*Enallagma elongatum**	Spiny Blue Damselfly	S
*Orthetrum abbotti**	Abbott's Skimmer	I
*Sympetrum fonscolombii**	Red-veined Darter	P
*Elattoneura glauca**	Common Threadtail	S/P
Platycypha caligata	Glade Jewel	S

This is the total recorded in this study. Some of these (with asterix) are very rare and unlikely to be seen by a casual visitor to the botanical gardens, only 25 were, in the end, selected for inclusion in the dragonfly trail brochure. P = Pond species, S = Stream species, S/P = Stream/Pond species, I = indeterminate as at time of recording.

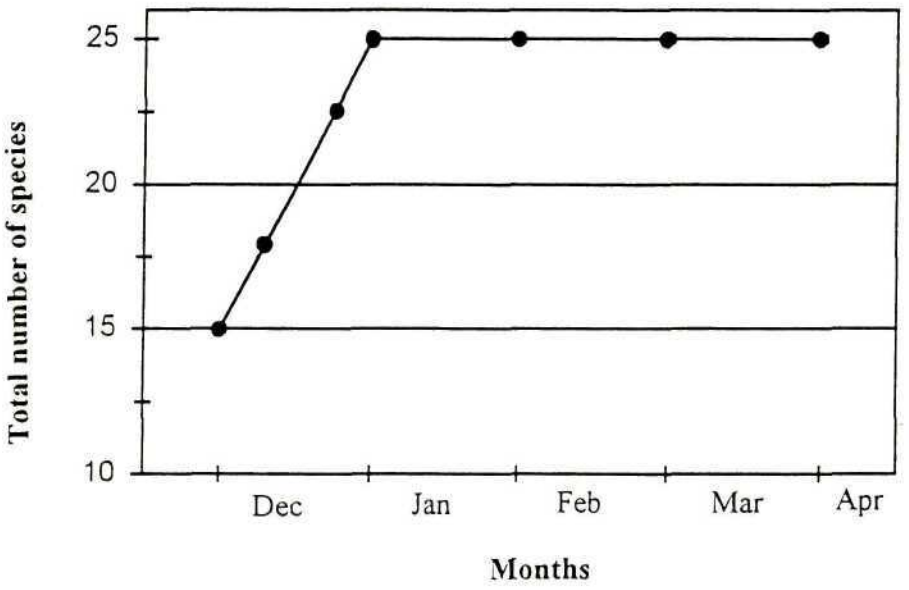


Fig. 32: Cumulative species curve for the focal (most abundant) 25 Odonata species collected from December to April.

4.7.2 Usefulness of public awareness survey

Since children and the elderly were among visitors most interested in knowing about dragonflies, emphasis during the final trail design was on making the trail enjoyable and educational, with rest points at dragonfly hotspots. More of the public were 'unknowing' of dragonflies than those 'not at all interested'. The latter category may have been as a result of simple lack of background knowledge, and, in response, an introductory leaflet (among the most preferred support media) was used to introduce the public to dragonflies. This leaflet was sold at the highly affordable price of R1.00. As most visitors were committed to knowing more about dragonflies by walking a dragonfly trail, this further justified the objectives of this study.

4.7.3 Implementation of trail

Popularity of the trail was investigated both through the questionnaire and sales of the introductory leaflet. The introductory leaflet was entitled: Damselflies and Dragonflies in the Botanical Gardens; a copy of which is enclosed in the back pocket of this thesis. In this leaflet, the first two dragonfly hotspots on the trail (the open lily pond at the entrance into the botanical gardens, the shady lily pond, and stream in the forest patch respectively), were referred to.

In the leaflet, each hotspot is briefly described, with a list of its characteristic dragonflies and damselflies. Salient but very brief biological information such as body colour, perching sites, drawings of copulatory behavior in dragonflies and their larval stages are also given. One-hundred copies of these introductory leaflets were sold in six weeks, which was very encouraging.

Currently, a new and bigger leaflet entitled: Botanical Gardens Dragonfly Trail has been designed to include all seven dragonfly hotspots, instead of only the first two as in the case of the introductory leaflet. This new leaflet contains photographs of the 25 commonest dragonfly species, and describes the trail in greater detail (see thesis pocket).

The trail (Appendix 11) was designed to begin at the pond on the left at the entrance into the botanical gardens (hotspot 1) through the meandering forested river (hotspot 7), returning to the point of origin (hotspot 1) via the plane tree avenue. It takes about an hour's gentle walk to cover all seven dragonfly hotspots. The seven hotspots, which covered the 25 focal species, were are as follows:

Hotspot 1 location: open water lily pond at the entrance into the botanical gardens, and is characterized by a variety of marginal vegetation and floating water lilies.
Typical dragonfly species: *P. massaicum, I. senegalensis, C. erythraea, P. flavescens.*

Hotspot 2 location: between a semi-permanent shady pond and a stream outlet situated in a forested patch of ferns and overhanging macrophytes, trees and marginal vegetation.
Typical dragonfly species: *A. leucosticta, C. tessellatus, O. julia, N. jonesi*

Hotspot 3 location: between hotspots 2 and 4. An ornamental pond less than 1 m deep and 2.5 m in diameter. This pond is used to demonstrate how a dragonfly pond can be made or maintained. Ponds can be made by lining an excavation with butyl, but this is expensive. They can also be made by damming small, streams even though ponds made this way are liable to nutrient pollution and/or frequent dredging. Ideally, individual ponds can be made by digging in an area underlain by impervious clay. Such an ornamental pond should be surrounded by a variety of marginal vegetation and floating lilies to encourage high species richness and buffer adverse environmental impacts e.g. dry and wet spells (Samways 1999).
Water levels should be maintained constant, as fluctuating levels can have an impoverishing effect (Samways 1999). Trees and bushes at the pond edge can, in most cases, result in leaves falling into the pond and depleting oxygen in water. Therefore, it is recommended that willows, or preferably an indigenous tree, should not be planted too close to ponds. If planting is close, the tree's growth must be frequently controlled (British Dragonfly Society 1993). Typical dragonfly species here are: *P. lucia, N. farinosa, E. glaucum* and *C. glabrum*.

Hotspot 4 location: an open semi-permanent lily pond with a large variety of aquatic weeds, sedges and rushes close to the Dorpspruit river (see trail map). This pond is a natural attractant to open pond dragonfly species e.g *E. glaucum, L. plagiatus, T. stictica*, and *T. arteriosa*.

Hotspot 5 location: at the adjoining marshland close to the dam.

The Dorpspruit river drains into this dam through the marsh. This dam serves as a refuge to some of South Africa's rare aquatic plants. It borders a forest and is rich in submerged and marginal vegetation. Open pond dragonfly species are typical of this biotope e.g. *P. massaicum, P. salisburyense, A. imperator, A. speratus*

Hotspot 6 location: at a 2.5 m high waterfall with a forested and grassy bank. The exposed rocks at this biotope among other substrates form ideal perching and basking sites for both pond and riverine dragonfly species. It also serves as a spillway that gives rise to the meandering river. Typical dragonfly species here are: *A. falcifera, P. kersteni, P. cognatus and Z. natalensis.*

Hotspot 7 location: at the meandering river with grassy, herbaceous and forested banks. This dragonfly biotope is also characterized by a high level of exposed rocks serving as shelter oviposition, perching and basking sites.

Typical dragonfly species here include: *P. hageni, P. caligata, T. dorsalis* and *Z. natalensis.*

Through consultation with the botanical gardens management, it was decided that each of the seven dragonfly hotspots on the trail will have information boards containing species photographs of four typical dragonfly species and a brief description of the biotope characteristics of each of these hotspots (see Appendix12: Recommendations for information boards at each of the seven dragonfly hotspots).

4.8 Comparison of the trail with others elsewhere

The trail design in this study is one of a few formal strategies so far designed to promote dragonfly awareness and education.

In Japan, postage stamps and credit cards called 'ecology cards' are used to promote and conserve plants and animals, with 0.05% of the amount of each purchase using the ecology card contributing to the nature conservation group e.g the *Tombo* 'dragonfly kingdom' in Nakamura, Kochi prefecture receives 0.05% of purchase made in this way (Eda 1995).

In Britain, three or four reserves have been set up, notably the Ashton Water Dragonfly Sanctuary designed principally to promote interest in dragonflies (Corbet 1993, 1999). Ponds are increasingly being used to introduce children and adults alike to biological principles (Moore 1997). They are exploitable and aesthetic, contributing to the quality of life, genetic biodiversity bank, recreation, tourism and water use (Boothby 1999).

Pond construction and management is also being encouraged in Britain by the British Dragonfly Society. In Japan, not only are ponds, lakes and rivers conserved, but ponds are also created for the purpose of propagating dragonflies and are artificially made and/or managed. A celebrated example of dragonfly biotope creation is the dragonfly sanctuary at Nakamura, Shikoku, established in 1985 by M. Sugimura and sponsored by the city of Nakamura and the Japanese branch of the World Wide Fund for Nature (Ishikawa 1987; Moore 1987). Occupying more than 50 ha of swamps and abandoned rice fields surrounded by low hills bearing mixed forest, this reserve is being managed successfully, to provide habitats for more than 70 species of dragonflies and was visited by 50 000 people in 1990 (Inoue 1991; Asahina 1992). More than 20 other sanctuaries managed expressly to promote dragonfly awareness exist in Japan, mainly in the southern parts of Honshu (Eda 1995; Corbet 1999).

The National Botanical Gardens in Pietermaritzburg has a rich selection of water bodies which provides a highly heterogenous collection of dragonfly biotopes. Being a protected area, these dragonfly biotopes are buffered from any local anthropogenic disturbances or exploitation. The botanical gardens serve as a scientific research site as well as being highly aesthetic and valuable for recreation. Consequently, it is likely to attract a high number of dragonfly enthusiasts each year. The average number of visitors per month this year stands at 6000 (Curator per comm), hence making this site useful for promoting dragonfly awareness and education using the dragonfly trail designed. This responds to section 5:4 of the IUCN Status Survey and Conservation Action Plan: Dragonflies, which states that: "The effectiveness of protected areas and conservation outside them, the effectiveness of legislation and pollution control all depend upon public demand and hence upon education and raising awareness (IUCN/SSC Odonata Specialist Group 1997)".

4.9 FURTHER RECOMMENDATIONS

4.9.1 Trail design

i) Production and sales of a definitive but up-datable dragonfly species/biotope information leaflet and, in the future, a poster with perhaps 30 species of the Drakensberg and KwaZulu-Natal midlands. This is a wide geographical area with considerable tourist appeal. Sales of photographs and slides would also enhance the profile of the trail.

ii) Sale of the guide book Dragonflies of the Drakensberg (Samways and Whiteley, 1997) at the main gate. This inexpensive book covers most of the species in the botanical gardens.

iii) It is necessary to know just how successful the trail has been. In this regard, it is essential to review the success of the trail, say, in a year's time, by re-interviewing the public.

iv) Advertisement of trail in association with the Midlands Meander, which is a high-profile tourist circuit and well-known to national and international tour operators.

4.9.2 Biotope management

1) Manage for heterogeneity i.e maintain a wide range of biotopes (especially with various types of vegetation physiognomy). This encourages species richness, and also buffers against adverse environmental impacts, especially long, dry spells.

2) Maintain constant water levels in the dam, marshes and open ponds. Fluctuating levels have a strong impoverishing effect. The dam currently needs to be partially dredged as the current influx of mud is filling it up rapidly, and soon it will be a braided weed-choked stream (which is likely to encourage a smaller, less diverse, dragonfly assemblage).

CHAPTER 5

CONCLUSIONS

There were high populations of dragonflies from November to June, with peak occurrences from December to April. However, biotope-tolerant species like *P. kersteni, P. salisburyense, E. glaucum, L. plagiatus, C. glabrum, O. julia* and *C. erythraea* occurred throughout most of the year. In both summer and winter seasons, dragonfly species were most easily seen just before or after noon on warm, sunny days.

Six significant environmental variables were important in separating the 20 a priori selected sampling units into four dragonfly biotopes namely: 'waterfall', 'forested river', 'shady pond/stream' and 'open ponds/dam', with highest species richness and diversity being in the sunlit, open ponds/dam biotope. Different Anisoptera and Zygoptera species showed varying degrees of response to all significant environmental variable gradients. The resultant four biotope types were highly heterogenous, which encouraged a high species richness and diversity in the Botanical Gardens landscape. Both regionally rare and abundant, as well as localized and widespread dragonfly species, were recorded.

Visitors to the Botanical Gardens were from all age groups, and were aware and committed to learning more about dragonflies and their habitats using a trail. This was especially so for children and the elderly. With information from the analyses of ecological data, as well as responses to a questionnaire, a trail was designed with seven dragonfly hotspots. Such a trail is both for educating and raising of public awareness of all age groups on dragonflies, their biotopes and their conservation. Leaflets, photographs, posters, guides and slides (in that order of preference) were found to be popular media in this regard.

Most dragonfly species could not be seen during winter months but, species such as *P. kersteni, P. salisburyense, E. glaucum, C. glabrum, L. plagiatus, O. julia* and *C. erythraea* were found to be biotope-tolerant and appeared throughout the year. Consequently, the trail designed during this study may be useful throughout the year, but most effective during species-rich, mid-summer months.

Although a valuable exercise in design of future trails (species lists can be determined by four visits during one of the mid-summer months), such intensive research, as carried out here, will not be necessary. It is critical to work with the managers of the focal reserve (in this case, the National Botanical Gardens, Pietermaritzburg) to ascertain what is feasible and practicable in the design of a dragonfly awareness trail.

REFERENCES

Arai, Y. 1991. On the drought and cold resistance of *P. flavescens* at the year's end. *Gracile* **31**:20-22.

Asahina, S. 1992. *Regional report*: Japan. In Moore 1992.

Baker, G. 1997. A framework for the future: green networks with multiple uses in and around towns and cities. In *English Nature Research Reports* No. **256**: 8-9.

Begg, C. 1986. The Wetlands of Natal (Part1). The Natal Town and Regional Planning Commission, Pietermaritzburg.

Boothby J. 1999. Framing a strategy for pond landscape conservation: aims, objectives and issues. *Landscape Research* **24**:67-83.

Bray, J. R. and Curtis J.T. 1957. An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs* **27**: 325-349.

Bridges, C. A. 1994. Catalogue of the family-group, genus-group and species-group names of the Odonata of the world (3rd edn). Urbana, Illinois, USA.

British Dragonfly Society. 1993. Managing habitats for dragonflies. British Dragonfly Society, Purley, United Kingdom.

Brooks, S.J. 1993. Review of a method to monotor adult dragonfly populations. *Journal of the British Dragonfly Society* **9**: 1-4.

Brown, K.S. 1991. Conservation of neo-tropical environments: insects as indicators. In *The Conservation of Insects and their Habitats* (eds N. M. Collins and J. A. Thomas). Pp 350-404 Academic Press, London.

Buchwald, R. 1992. Vegetation and dragonfly fauna-characteristics and examples of biocenological field studies. *Vegetatio* **101**:99-107.

Butt, M. 1995. Odonata Collected from the Tambopata Candamo Reserve Zone, South eastern Peru. *Notulae Odonatologicae* **4**:93-97.

Carchini, G. and Rota, E. 1985. Chemico-physical data on the habitats of rheophile Odonata from central Italy. *Odonatologica* 25:73-77.

Clark, T.E. and Samways, M. J. 1996. Dragonflies (Odonata) as indicators of biotope quality in the Kruger National Park, South Africa. *Journal of Applied Ecology* **33**:1001-1012.

Clark, K.R. and Warwick, R.M. 1994. Changes in marine communities: an approach to statistical analysis and interpretation. Plymouth Marine Laboratory, UK.

Clark, D.J, Hewitt, S.M, Smith, E.M and Smith, R.W.J. 1990. Observations on the breeding habits and habitats of *Aeshna caerulea* (Strom) in Scotland. *Journal of the British Dragonfly Society* **6**:24-29.

Corbet, P.S. 1993. Are Odonata useful as bioindicators? *Libellula* **12**: 9-102.

Corbet, P.S. 1993. The first ten years of the British Dragonfly Society. *Journal of the British Dragonfly Society* **9**: 25-25-39.

Corbet, P. S. 1962. A Biology of Dragonflies. Witherby, London.

Corbet, P.S., Longfield, C. and Moore, N.W. 1960. Dragonflies. Collins, London.

Corbet P.S. 1999. Dragonflies: Behaviour and Ecology of Odonata. Harley Books. Colchester, Essex, England.

Council of Europe, 1989. On the evolution and conservation of hedgerow landscapes (bocages) in Europe. Council of Europe. *Nature and Environment Series*. No. **40.** Strasbourg.

Countryside Commission. 1996. Green Capital: Planning for London's greenspace. *English Nature*. London Wildlife Trust, Cheltenham.

Danielson, B.J. 1992. Habitat selection, interspecific interactions and landscape composition. *Evolutionary Ecology* **6**: 399-411.

Dempster, J.P. 1989. Insect introductions: natural dispersal and population persistence in insects. *The Entomologist* **108**: 5-13.

Digby, P.N. and Kempton, R.A. 1987. Multivariate analytical of ecological communities. Chapman and Hall, New York.

Disney, R. H. L. 1986. Assessments using invertebrates: Posing the problem. In Wildlife Conservation Evaluation (ed. M.B Usher) Pp 271-293. Chapman and Hall, London.

Drewett, J. 1988. Never mind the whale, save the insect. *New Scientist* **120**: 32-35.

Eda, S. 1995. The conservation of Dragonflies including endangered/ vulnerable species in Japan. In Proceedings of the International Symposium on the Conservation of Dragonflies and their Habitats. (eds P.S, Corbet, S.W. Dunkle, and H. Ubukata). Pp 19-22. Japanese Society for the Preservation of Birds, Kushiro.

Ehrlich, P.R. 1992. Population biology of checkerspot butterflies and the research of global biodiversity. *Oikos* **63**: 6-12.

Erwin, T.L. 1991. An evolutionary basis for conservation strategies. *Science.* **253**: 750-752.

Forman, R.T.T. 1991. Landscape Corridors : from theoretical foundations to public policy. In *Nature Conservation 2.* (eds D.A. Saunders and R.J. Hobbs). Pp 71-84. Chipping Norton, Surrey Beatty.

Forman, R.T.T and Godron, M. 1981. Patches and structural components for a landscape ecology. *Bioscience* **31** : 733-740.

Fry, R. and Londsdale, D. (eds). 1991. Habitat conservation for insects- a neglected green issue. The Amateur Entomologists' Society, Middlesex, England.

Gaston, K. J. 1992. Regional numbers of insect and plant species. *Functional Ecology* **6**: 243- 247.

Gauch, H.G. 1982b. Noise reduction by eigenvector ordination. *Ecology* **63**: 1643-1649.

Gonzalez-Soriano, E. 1987. *Dythemis cannacrioides* Calvert, a libellulid with unusual ovipositing behaviour (Anisoptera). *Odonatologica* **16**:175-182.

Groombridge, B. (ed.) 1992. Global Biodiversity: Status of the Earth's Living Resources. Chapman and Hall, London.

Hämäläinen H. and Huttunen, P. 1990. Estimation of acidity by means of benthic invertebrates: evaluation of two methods. In Acidification in Finland. (eds P.Kauppi, P. Anttilla and K. Kenttämies). Pp 1051-1070. Springer Verlag, Berlin.

Hawking J.H. and New T.R. 1999. The distribution patterns of dragonflies (Insecta:Odonata) along the Kiewa River, Australia, and their relevance in conservation assessment. *Hydrobiologia* **392**: 249-260.

Howard-Williams, C. 1980. Aquatic macrophytes of the coastal wetlands of Maputaland. In Studies on the ecology of Maputaland. (eds M.N. Bruton and K.H. Cooper). Pp 42-51. Rhodes university and the Natal Branch of the Wildlife Society of S/A, South Africa.

Henning, S.F. & Henning, G.A. 1989. South African Red Data- Butterflies. *South African National Scientific Programs Report*. CSIR, Pretoria.

Ingham, D. S. 1996. Application of fragmentation and vegetation models to epigaeic invertebrates in South Africa. *Conservation Biology* **10**: 1353-1358.

Inoue, K. 1991c. *Regional report*: Japan. Oral addendum to report by S. Asahina. In N.W. Moore, 1991d.

Ishikawa, Y. 1987. Scene in Japan: a dragonfly Sanctuary. *Time, 21 September*. (From Corbet 1999).

IUCN, 1996. 1996 IUCN Red List of Threatened Animals. IUCN, Gland, Switzerland and Cambridge, United Kingdom.

James, F.C. and McCulloch, C.F. 1990. Multivariate analysis in ecology and systematics:Pannacea or Pandora's box? *Annual Review of Ecology and Systematics.* **12**: 129-166.

Jongman, R.H. Ter Braak, C.J.F. and Van Tongeren, O.F.R. 1987. Data analysis in community and landscape ecology. Centre for Agricultural publishing and Documentation (Pudoc), Wageningen.

Ludwig, J. A. and Reynolds. J.F. 1988. Statistical ecology: a primer on methods and computing. John Wiley and Sons, New York.

Lindenmayer, D.B., Nix, H.A., McMahon, J.P., Hutchinson, M.F. and Tanton, M.T. 1991. The conservation of Leadbeater's possum, Gymnobelideus leadbeateri (McCoy): A case study of the use of bioclimatic modelling. *Journal of Biogeography* **18**: 371-383.

Machado, A. 1989. O menino e o rio. Edita Le. Belo Horizonte.

Mandelbrot, B. B. 1983. The Fractal Geometry of Nature. Freeman, New York.

McGeoch, M. A. & Samways, M.J. 1991. Dragonflies and the thermal landscape: Implications for their conservation (Anisoptera). *Odonatologica* **20**: 303-320.

Miller, P.L. 1987. Dragonflies. Camridge University Press, Cambridge.

Moore, N.W. 1976. The Conservation of Odonata in Great Britain. *Odonatologica* **5**: 37-44.

Moore, N.W. 1991b. Observe extinction or conserve diversity? In *The Conservation of Insects and their Habitats* (eds N. M. Collins and J.A. Thomas). Pp 1-8. Academic Press, London.

Moore, N. W. 1982. Conservation of Odonata- first steps towards a world strategy. *Advances in Odonatology* **1**: 205-211.

Moore, N. W. 1987. A most exclusive preserve. *New Scientist* **115**: 65.

Moore, N. W. 1992. Report of the 7th meeting of the IUCN Odonata Specialist Group. *Rep. Odonatol. Specialist Group IUCN 9.* 22Pp.

Moore, N. W. 1991d. Report of the 6th meeting of the IUCN Odonata Specialist Group. *Rep. Odonatol. Specialist Group IUCN 7.* 19Pp

Moore, N. W. 1991a. The development of dragonfly communities and the consequences of territorial behaviour: a 27- year study on small ponds at Woodwalten Fen, Cambridgeshire, U.K. *Odonatologica* **20:**203-231.

Moore, N.W. (Compiler). 1997. Dragonflies- Status Survey and Conservation Action Plan. IUCN/SSC Odonata Specialist Group. IUCN, Gland, Switzerland and Cambridge, United Kingdom.

Nagase, K. 1983. The disappearance of *P. flavescens* larvae. *Gracile* **45**: 10-12.

Odum, E. P., Connell, C.E. and Davenport, L. B. 1962. Population energy flow of three primary consumer components of three of old-field ecosystems. *Ecology* **43**: 88-96.

Ormerod, S.J.,Wade, K.L. and Gee, A.S. 1987. Macro-flora assemblages in upland Welsh streams in relation to acidity and their importance to invertebrates. *Freshwater Biology* **18**:545-557.

Osborn, R. 1995. Niche and life-history differences in five highly sympatric species of Trithemis dragonflies (Odonata:Libellulidae). Unpublished M.Sc thesis. Department of Zoology and Entomology, University of Natal, Pietermaritzburg.

Osborn R. and Samways M. J. 1996. Determinants of adult dragonfly assemblage patterns at new ponds in South Africa. *Odonatologica* **25**: 49-58.

Pinhey, E.C.G. 1951. The dragonflies (Odonata) of Southern Africa. *Transvaal Museum Memoirs*, **5**:1-335.

Pinhey, E. 1978. Odonata. In Biogeography and Ecology of Southern Africa.(eds M.J.A. Werger and A.C. Bruggen). Pp 723-731. Junk, The Hague.

Pinhey, E. 1984. A survey of dragonflies (Odonata) of southern Africa. Part I. *Journal of the entomological Society of southern Africa* **47**:147-188.

Ratcliffe, D.A. (ed.) 1977. A Nature Conservation Review. Cambridge University Press, Cambridge.

Samways, M. J. and Steytler, N.S. 1996. Dragonfly (Odonata) distribution patterns in urban and forest landscapes and recommendations for riparian management. *Biological Conservation*. **78**: 279-288.

Samways M.J. and Whiteley, G. 1997: Dragonflies of the Natal Drakensberg. Ukhahlamba Series, No.6: 88Pp. University of Natal Press, Pietermaritzburg.

Samways, M.J., Osborn R. and Van Heeden I. 1996. Distribution of benthic invertebrates at different depths in a shallow reservoir in the KwaZulu-Natal Midlands. *Koédoe* 39:69-76.

Samways, M.J. 1989a. Farm dams as nature reserves for dragonflies (Odonata) at various altitudes in the Natal Drakensberg Mountains, South Africa. *Biological Conservation* **48**: 181-187.

Samways, M. J. 1995. Conservation of the threatened endemic dragonflies of southern Africa. In Proceedings of the International Symposium on the Conservation of Dragonflies and their habitats. (eds P.S Corbet, S.W. Dunkle and H. Ubukata). Pp 8-15. Japanese Society for the preservation of Birds, Kushiro.

Samways, M.J. 1994. Insect Conservation Biology. Chapman and Hall, London.

Samways, M.J. 1993. A spatial and process sub-regional framework for insect and biodiversity conservation research and management. In *Perspectives on Insect Conservation* (eds K.J. Gaston, T.R New and M. J. Samways). Pp 1-27. Intercept, U.K.

Samways, M.J. and Caldwell, P. 1989. Flight behavior and mass feeding swarms of *Pantala flavescens* (Fabricius) (Odonata: Anisoptera: Libellulidae). *Journal of the entomological Society of southern Africa* **52**: 326-328.

Samways, M.J., 1992. Dragonfly conservation in South Africa: a biogeographical perspective. *Odonatologica* **21**: 165-180.

Samways, M.J., 1993. Dragonflies (Odonata) in taxon overlays and biodiversity conservation. In Perspectives on Insect Conservation (eds K.J. Gaston, T.R. New and M.J. Samways).Pp 111-123. Intercept, UK.

Samways, M.J. 1999. Diversity and conservation status of south African dragonfles (Odonata). *Odonatologica* **28**: 1-116.

Sant, G.J. and New, T.R 1988. The Biology and Conservation of Hemiphlebia mirabilis Sélys (Odonata, Hemiphlebiidae) in Southern Victoria. Arthur Rylah Institute for Environmental Research, *Technical Report Series*, **No. 82**. Victoria. Australia.

Schmidt, E. 1985. Habitat inventorisation, characterization and bio-indication by a "Representative Spectrum of Odonata species (RSO)". *Odonatologica* **14**:127-133.

Scholtz, C.H. 1990b. Review of 'Biotic Diversity in Southern Africa': Concepts and conservation.' (ed. B.J. Huntley). *South African Journal of Zoology* **25**:152-153.

Scholtz, C.H. and Chown, S.L. 1993. Insect conservation and extensive agriculture: the savanna of Southern Africa. In *Perspectives on Insect Conservation* (eds R.J Gaston, T.R.New and M. .J. Samways). Pp 75-95. Intercept, U.K.

Shirt, D. B. (ed). 1987. British Red Data Books 2 Insects. Nature Conservancy Council, London.

Soule, M. E. 1991. Conservation: tactics for a constant crisis. *Science* **253**: 744-750.

Spellerberg, 1991. Monitoring Ecological Changes. Cambridge University press, Cambridge.

Southwood, T.R.E. 1978. Ecological methods: with particular reference to the study of insect populations. 2nd edn. Chapman and Hall, New York.

Stewart, D.A. B. and Samways, M. J. 1998. Conserving dragonflies (Odonata) assemblages relative to river dynamics in a major African savanna game reserve. *Conservation Biology* **12**:683-692.

Steytler, N.S. and Samways, M.J. 1994. Biotope selection by adult male dragonflies (Odonata) at an artificial lake created for insect conservation in South Africa. *Biological Conservation* **17**: 381-386.

Strong, D.R., Lawton J.H. and Southwood, T.R.E. 1984. Insects on Plants: Community Patterns and Mechanisms. Blackwell, Oxford.

Steytler, N.S. 1994. Dragonfly distribution patterns relative to forest and urban landscapes. Unpublished M.Sc thesis. University of Natal, Pietermaritzburg.

Ter Braak, C.J.F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* **67**: 1167-1179.

Ter Braak, C.J.F. 1988. CANOCO- a FORTRAN program for canonical community ordination by partial detrended canonical correspondence analysis, principal component analysis and redundancy analysis (version 2.1). *Agricultural Mathematics Group Technical Report*: LWA - 88-02, Wageningen, Netherlands.

Thomson, S.K. 1992. Sampling. John Wiley and Sons, New York.

Thorp, J.H. and Diggins, M.R. 1982. Factors affecting depth distribution of dragonflies and other benthic insects in a thermally destabilized reservoir. *Hydrobiologia* **87**:33-44.

Van Tol, J. Verdonk, M.J. 1988. The Protection of Dragonflies (Odonata) and their Biotopes. European Committee for the Conservation of Nature and Natural Resources, Strasbourg.

Von Eislöffel, F., Niehuis, M. and Weitzel, M.(eds). 1992. Rote Liste der bestandsgefahrdeten Libellen (Odonata) in Rheinland-Pfalz. Ministerium fur Umwelt, Mainz.

Wardle, D.A. 1999. Biodiversity, ecosystems and interactions that transcend the interface. *Trends in Ecology and Evolution* 14:125-126.

Watson, J.A.L. Arthington, A.H. and Conrick, D.L. 1982. Effect of sewage effluent on dragonflies (Odonata) of Bulimba Creek, Brisbane. *Australian Journal of Marine and Freshwater Research* **33**:517-528.

Webb, N.R. 1989. Studies on the invertebrate fauna of fragmented heathland in Dorset, U.K and the implication for conservation. *Biological conservation* **47**:153-165.

Weir, J.S. 1974. Odonata collected in and near seasonal pools in the Wankie national Park, Rhodesia, with notes on the physio-chemical environments in which nymphs were found. *Journal of the Entomological society of Southern Africa* **37**:135-145.

Wood, P.A and Samways, M.J. 1991. Landscape element patterns and continuity of butterfly flight paths in an ecologically landscaped botanical garden, Natal, South Africa. *Biological Conservation* **58**:149-166.

APPENDICES

Appendix 1. Monthly totals of each species throughout the one-year study period.

Species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
E. glaucum	65	34	28	73	49	48	58	27	67	115	83	60
L. plagiatus	35	28	25	12	12	19	46	74	63	59	54	49
O. julia	52	56	36	18	3	13	26	37	61	90	66	71
T.dorsalis	7	7	0	0	0	4	7	7	18	16	21	17
P. caligata	9	7	2	0	0	0	3	11	12	15	9	16
P. lucia	19	9	2	1	0	0	0	0	1	5	24	43
P. jucunda	2	2	0	0	0	0	0	0	0	1	6	5
C. erythraea	25	35	11	12	53	63	30	25	25	38	42	45
T. arteriosa	24	11	1	1	0	0	22	50	51	29	34	32
P. kersteni	11	12	5	5	8	13	41	30	28	21	17	29
P. salisburyense	13	12	9	9	28	33	43	47	49	56	54	55
C. tessellatus	30	34	25	6	2	2	0	0	1	3	3	4
A. leucosticta	14	2	0	0	1	16	63	76	68	34	16	11
C. glabrum	20	11	3	0	4	1	46	66	70	72	80	55
O. caffrum	0	0	0	0	0	0	1	1	2	3	3	2
N. jonesi	2	5	1	1	0	0	2	9	14	13	14	13
P. iridipennis	0	0	0	0	2	0	0	0	0	0	0	0
A. imperator	0	1	2	0	6	12	8	6	3	7	7	9
N. farinosa	0	0	0	1	0	0	19	35	66	57	32	22
P. cognatus	0	0	0	0	0	0	4	3	2	6	15	7
P. flavescens	0	0	0	0	0	0	19	38	20	7	10	13
A. speratus	0	0	0	0	0	0	5	4	8	9	9	7
T. stictica	0	0	0	0	0	0	14	44	43	68	58	29
P. massaicum	0	0	0	0	0	0	19	36	26	19	51	21
Z. natalensis	0	0	0	0	0	0	3	2	3	4	7	5
A. falcifera	0	0	0	0	0	0	0	2	4	2	14	5
A. tristis	0	0	0	0	0	0	0	1	0	0	0	0
P. luminans	0	0	0	0	0	0	0	2	1	1	2	1
O. trinacrium	0	0	0	0	0	0	0	2	15	9	9	16
I. Senegalensis	0	0	0	0	0	0	0	9	11	15	10	16
P. hageni	0	0	0	0	0	0	8	12	10	20	5	5
E. elongatum	0	0	0	0	0	0	0	0	0	0	3	1
O. abbotti	0	0	0	0	0	0	0	0	2	2	2	1
S. fonscolombii	0	0	0	0	0	0	0	0	0	1	2	1
E. glauca	0	0	0	0	0	0	0	0	0	1	1	0
S	15	16	13	11	11	11	23	26	28	32	33	32
N	328	266	150	139	168	224	487	656	743	793	763	666

N.B. Spellings of species names follow Bridges (1994).

Appendix 2. Monthly totals of each Anisoptera species throughout the one-year study period

Species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
O. julia	52	56	36	18	3	13	26	37	61	90	66	71
T. dorsalis	7	7	7	0	0	4	7	7	18	16	21	17
P. lucia	19	9	9	1	0	0	0	0	1	5	24	43
P. jucunda	2	2	2	0	0	0	0	0	0	1	6	5
C. erythraea	25	35	35	12	53	63	30	25	25	38	42	45
T. arteriosa	24	11	11	1	0	0	22	50	51	29	34	32
O. caffrum	0	0	0	0	0	0	1	1	2	3	3	2
N. jonesi	2	5	5	1	0	0	2	9	14	13	14	13
A. imperator	0	1	1	0	6	12	8	6	3	7	7	9
N. farinosa	0	0	0	1	0	0	19	35	66	57	32	22
P. cognatus	0	0	0	0	0	0	4	3	2	6	15	7
P. flavescens	0	0	0	0	0	0	19	38	20	7	10	13
A. speratus	0	0	0	0	0	0	5	4	8	9	9	7
T. stictica	0	0	0	0	0	0	14	44	43	68	58	29
Z. natalensis	0	0	0	0	0	0	3	2	3	4	7	5
A. tristis	0	0	0	0	0	0	1	0	0	0	0	0
P. luminans	0	0	0	0	0	0	0	2	1	1	2	1
O. trinacrium	0	0	0	0	0	0	0	2	15	9	9	16
O. abbotti	0	0	0	0	0	0	0	0	2	2	2	1
S. fonscolombii	0	0	0	0	0	0	0	0	0	1	2	1
S	7	8	8	6	3	4	14	15	17	19	19	19
N	131	126	106	34	62	92	161	265	335	366	363	339

Appendix 3. Monthly totals of each Zygoptera species throughout the one-year study period

Species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
E. glaucum	65	34	28	73	49	48	58	27	67	115	83	60
L. plagiatus	35	28	25	12	12	19	46	74	63	59	54	49
P. caligata	9	7	2	0	0	0	3	11	12	15	9	16
P. kersteni	11	12	5	5	8	13	41	30	28	21	17	29
P. salisburyense	13	12	9	9	28	33	43	47	49	56	54	55
C. tessellatus	30	34	25	6	2	2	0	0	0	3	3	4
A. leucosticta	14	2	0	0	1	16	63	76	68	34	16	11
C. glabrum	20	11	3	0	4	1	46	66	70	72	80	55
P. iridipennis	0	0	0	0	2	0	0	0	0	0	0	0
P. massaicum	0	0	0	0	0	0	19	36	26	19	51	21
A. falcifera	0	0	0	0	0	0	0	2	4	2	14	5
I. senegalensis	0	0	0	0	0	0	12	8	10	20	5	5
P. hageni	0	0	0	0	0	0	0	0	0	0	3	1
E. elongatum	0	0	0	0	0	0	0	0	0	1	1	0
E. glauca	0	0	0	0	0	0	0	9	11	15	10	16
S	8	8	7	5	8	7	9	11	11	13	14	13
N	197	140	97	105	106	132	331	386	408	432	400	327

Appendix 4. Total number of individuals in each of the sampling units for the whole study period

Species	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
E. glaucum	0	3	3	8	16	26	23	26	18	290	35	13	5	70	13	8	29	53	30	35
L. plagiatus	0	2	0	3	10	39	27	28	49	52	3	0	5	7	12	18	54	67	52	45
O. julia	20	14	5	4	2	16	6	11	9	66	40	39	45	62	65	66	14	18	16	11
T. dorsalis	1	15	3	9	26	14	0	0	4	1	0	0	0	0	0	0	1	6	10	7
P. caligata	0	15	21	29	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. lucia	0	0	0	0	6	9	6	3	6	23	0	0	0	0	0	0	4	21	13	9
P. jucunda	0	0	1	0	1	4	1	2	1	2	0	0	0	0	0	0	1	0	2	0
C. erythraea	0	0	0	0	11	61	49	50	64	35	0	0	0	0	0	0	34	37	34	29
T. arteriosa	0	0	0	2	6	50	33	24	33	18	0	0	0	0	0	0	11	25	27	22
P. kersteni	0	0	0	1	11	39	21	28	17	9	4	1	0	4	6	0	12	20	21	16
P. salisburyense	37	24	19	36	15	13	8	7	6	2	13	2	2	13	60	84	13	12	8	11
C. tessellatus	0	0	0	0	0	0	0	0	0	0	15	8	17	15	51	14	0	0	2	0
A. leucosticta	2	60	57	7	3	0	0	0	0	0	33	9	13	28	53	21	1	0	0	0
C. glabrum	0	2	0	2	2	6	14	13	30	27	51	39	33	55	20	13	30	31	23	20
O. caffrum	0	0	0	0	0	5	0	0	2	5	2	0	0	5	1	3	1	2	1	2
N. jonesi	0	0	0	0	0	0	0	0	0	9	6	4	21	34	0	0	1	0	0	2
P. iridipennis	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
A. imperator	0	0	0	0	2	9	9	5	16	0	0	0	0	0	0	0	1	5	7	5
N. farinosa	0	0	0	0	4	42	25	21	34	7	0	0	0	0	0	0	23	32	35	25
P. cognatus	0	6	8	12	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. flavescens	0	0	1	2	4	14	11	8	18	7	0	0	0	0	0	0	5	12	13	12
A. speratus	0	0	0	0	5	7	3	8	5	2	0	0	0	0	0	0	0	5	8	8
T. stictica	0	0	0	0	1	34	20	19	34	36	0	0	0	0	0	0	14	24	31	10
P. massaicum	0	0	0	2	3	43	17	21	25	0	0	0	0	0	0	0	4	14	19	12
Z. natalensis	10	4	4	15	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A. falcifera	0	0	10	13	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A. tristis	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
P. luminans	0	0	0	0	0	2	2	3	1	0	0	0	0	0	0	0	0	0	0	0
O. trinacrium	0	0	0	0	1	2	0	0	1	0	0	0	0	0	0	0	0	2	4	2
I. Senegalensis	0	2	7	13	7	2	0	0	0	0	0	0	0	0	3	5	2	2	3	3
P. hageni	0	6	2	0	0	0	0	0	0	0	10	3	17	14	3	3	0	0	0	0
E. elongatum	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O. abbotti	0	0	0	0	0	1	1	1	2	0	0	0	0	0	0	0	0	2	0	0
S. fonscolombii	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1
E. glauca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S	5	12	13	17	25	24	18	18	22	17	11	9	9	12	11	10	20	20	22	22
N	57	153	141	161	216	440	276	279	376	591	212	118	158	309	287	235	255	390	360	289

Appendix 5. Total number of Anisoptera individuals in each of the sampling units for the whole study period

Species	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
O. julia	7	14	5	4	2	16	6	11	9	34	52	25	20	43	53	51	14	18	16	11
T. dorsalis	1	15	3	9	26	14	0	0	4	1	0	0	0	0	0	0	1	6	10	7
P. lucia	0	0	0	0	6	9	6	3	6	23	0	0	0	0	0	0	4	21	13	9
T. jucunda	0	0	1	0	1	4	1	2	1	2	0	0	0	0	0	0	1	0	2	0
C. erythraea	0	0	0	0	11	61	49	50	64	35	0	0	0	0	0	0	34	37	34	29
T. arteriosa	0	0	0	2	6	50	33	24	33	18	0	0	0	0	0	0	11	25	27	22
O. caffrum	0	0	0	0	0	5	0	0	2	5	2	0	0	5	1	3	1	2	1	2
N. jonesi	0	0	0	0	0	0	0	0	0	9	6	4	21	34	0	0	1	0	0	2
A. imperator	0	0	0	0	2	9	9	5	16	0	0	0	0	0	0	0	1	5	7	5
N. farinosa	0	0	0	0	4	42	25	21	34	7	0	0	0	0	0	0	23	32	35	25
P. cognatus	0	6	8	12	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. flavescens	0	0	1	2	4	14	11	8	18	7	0	0	0	0	0	0	5	12	13	12
A. speratus	0	0	0	0	5	7	3	8	5	2	0	0	0	0	0	0	0	5	8	8
T. stictica	0	0	0	0	1	34	20	19	34	36	0	0	0	0	0	0	14	24	31	10
Z. natalensis	10	4	4	15	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A. tristis	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
P. luminans	0	0	0	0	0	2	2	3	1	0	0	0	0	0	0	0	0	0	0	0
O.trinacrium	0	0	0	0	1	2	0	0	1	0	0	0	0	0	0	0	0	2	4	2
O. abbotti	0	0	0	0	0	1	1	1	2	0	0	0	0	0	0	0	0	2	0	0
S. fonscolombii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S	3	4	6	6	14	16	12	12	16	12	3	2	2	3	2	2	12	13	13	14
N	18	39	22	44	110	271	166	155	231	179	60	29	41	82	54	54	110	191	201	146

Appendix 6. Total number of Zygoptera individuals in each of the the sampling units for the whole study period.

Species	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
E. glaucum	0	3	3	8	16	26	23	26	18	290	35	13	5	70	13	8	29	53	30	35
L. plagiatus	0	2	0	3	10	39	27	27	49	52	3	0	5	7	12	18	54	67	52	45
P. caligata	0	15	21	29	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. kersteni	0	0	0	1	11	39	21	28	17	9	4	1	0	4	6	0	12	20	21	16
P. salisburyense	37	24	19	36	15	13	8	7	6	2	13	2	2	13	60	84	13	12	8	11
C. tessellatus	0	0	0	0	0	0	0	0	0	0	15	8	17	15	51	14	0	0	2	0
A. leucosticta	2	60	57	7	3	0	0	0	0	0	33	9	13	28	53	21	1	0	0	0
C. glabrum	0	2	0	2	2	6	14	13	30	27	51	39	33	55	20	13	30	31	23	20
P. iridipennis	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
P. massaicum	0	0	0	2	3	43	17	21	25	0	0	0	0	0	0	0	4	14	19	12
A. falcifera	0	0	10	13	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
I. senegalensis	0	2	7	13	7	2	0	0	0	0	0	0	0	0	3	5	2	2	3	3
P. hageni	0	6	2	0	0	0	0	0	0	0	10	3	17	14	3	3	0	0	0	0
E. elongatum	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
E. glauca	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
S	2	8	7	11	10	7	6	6	6	5	8	7	7	9	9	8	8	7	8	8
N	39	114	119	118	105	168	110	122	145	380	164	75	92	208	221	166	145	199	158	143

Appendix 7. Environmental data arranged for the 20 sampling units (SU1- SU20) May 1998 - April 1999.

SU	At	pH	At	Wt	Wd	%Sh	RIVeg	WFVeg	DRVeg	SPPVeg	OSTVeg	OPPVeg
S1	62.5	7.1	30.2	23.5	6.5	55	100	0	0	0	0	0
S2	60	7.1	29.9	22.9	6.8	40	100	0	0	0	0	0
S3	60	7.2	29.9	22.7	6.5	40	100	0	0	0	0	0
S4	60	7.2	31.6	22.9	6.3	25.5	100	0	0	0	0	0
S5	63.8	7.2	31.6	23.1	3.8	0	0	100	0	0	0	0
S6	61.3	6.9	32.6	23.2	20.5	0	0	0	80	0	0	0
S7	61.3	6.8	32.6	23.2	20.8	0	0	0	90	0	0	0
S8	63.8	6.9	32.8	23.2	21	0	0	0	98	0	0	0
S9	62.5	6.9	33	23.2	17.5	0	0	0	95	0	0	0
S10	67.5	6.8	33.1	23.3	18.5	0	0	0	0	55	0	0
S11	37.5	7.2	25.5	18.2	1.3	55	0	0	0	85	0	0
S12	52.5	7.3	25.5	18.4	2.3	67.5	0	0	0	100	0	0
S13	57.5	7.3	26.2	18.3	3	67.5	0	0	0	100	0	0
S14	55	7	26.3	19.6	5.3	40	0	0	0	95	0	0
S15	27.5	7.2	27.1	20.1	2.3	47.5	0	0	0	0	95	0
S16	27.5	7.2	27.9	20.3	2.5	5.5	0	0	0	0	98	0
S17	60	6.9	31.8	22.3	19.3	0	0	0	0	0	0	100
S18	60	6.9	31.9	22.3	21	0	0	0	0	0	0	65
S19	62.5	6.9	32.3	22.4	20.1	0	0	0	0	0	0	85
S20	67.5	6.9	32.8	22.4	21.3	0	0	0	0	0	0	98

SU = sampling unit, Tu = turbidity, At = atmospheric temperature, Wt = water temperature,
Wd = water depth, %Sh = percentage shade
See section 2.3.1 for full meanings of : RIVeg, WFVeg, DRVeg, SPPVeg, SOSTVeg, OPPVeg.

Appendix 8. Sampling unit species diversity measures during the one-year study period.

Div.M		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
R1		0.98	2.2	2.4	3.1	4.4	3.8	3.1	3.2	3.5	2.5	1.8	1.7	1.6	1.9	1.8	1.7	3.4	3.2	3.6	3.7
H'		1.1	1.9	1.9	2.4	2.8	2.7	2.6	2.6	2.6	1.8	2	1.7	1.9	2.1	1.9	1.8	2.4	2.6	2.7	2.7
J'		0.64	0.77	0.75	0.85	0.86	0.85	0.89	0.88	0.84	0.64	0.83	0.78	0.9	0.84	0.82	0.78	0.81	0.88	0.89	0.88
λ		0.45	0.21	0.21	0.11	0.07	0.07	0.08	0.08	0.09	0.2	0.15	0.22	0.15	0.14	0.16	0.22	0.11	0.09	0.07	0.08
N1		2.8	6.9	6.9	11.1	16.2	14.9	12.9	13.3	13.6	6.2	7.4	5.6	7.3	8.3	7.1	6.1	11.5	13.7	15.5	15.3
N2		2.2	4.9	4.7	8.9	13.2	12.6	11.2	11.4	11.3	3.4	6.3	4.5	6.8	6.9	6.1	4.5	9.3	11.5	13.5	12.9
	S	5	12	13	17	25	24	18	18	22	17	11	9	9	12	11	10	20	20	22	22
	N	57	153	141	161	216	440	276	279	376	591	212	118	158	309	287	235	255	390	360	289

Div. M = Diversity measure, R1 = Margalef's richness index, H' = Shannon diversity index,
J' = Pielou's evenness index, λ = Simpson's index, N1 and N2 = Hill's diversity numbers.

Appendix 9. Monthly species diversity measures during the one-year study period.

Div.M		May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
R1		2.42	2.69	2.39	2.03	1.95	1.85	3.39	4.01	4.08	4.64	4.82	4.77
H'		2.41	2.38	2.04	1.6	1.77	1.99	2.73	2.82	2.89	2.88	3.02	3.03
J'		0.89	0.85	0.79	0.66	0.73	0.83	0.88	0.85	0.86	0.83	0.86	0.87
λ		0.11	0.11	0.15	0.13	0.22	0.17	0.08	0.07	0.07	0.07	0.06	0.05
N1		11.2	11.8	1.7	4.9	5.8	7.3	15.3	16.8	17.9	17.8	20.5	20.7
N2		9.5	8.8	6.5	3.2	4.2	6.1	13.2	14.3	15.4	13.8	16.4	17.2
	S	15	16	13	11	11	11	23	27	28	32	33	32
	N	328	266	150	139	168	224	487	656	743	793	763	666

Div. M = Diversity measure, R1 = Margalef's richness index, H' = Shannon diversity index, J' = Pielou's evenness index, λ = Simpson's index, N1 and N2 = Hill's diversity numbers.

Appendix 10: Dragonfly Conservation Research Questionnaire

Administered by the Invertebrate Conservation Research Centre, University of Natal in collaboration with the National Botanical Gardens, Pietermaritzburg, this survey aims at assessing public awareness(visitors to the botanic gardens) with respect to dragonflies. Information obtained from this assessment will be used to design conservation strategies for these insects.

Instructions: Please kindly tick the brackets with the appropriate answer. Thank you.

1.Which of the age groups do you belong to?
[1-12] [13-19] [36-60]
[20-35] [61 and above]

2.Have you ever been to this garden before?
[Yes] [No]

3.If No, are you interested in dragonflies?
[Yes] [No] [Don't know what they are]

4.If Yes, have you ever seen dragonflies in this garden before?
[Yes] [No] [Don't know what they are]

5.What are their colours?
[Red] [Multicoloured] [No idea]
[White] [All types of colours]

6.What is the difference between dragonflies and damselflies?

[Dragonflies are smaller and more fragile than damselflies] [No idea]

[Dragonflies are bigger and stronger than damselflies]

7.Imagine a friend of yours who is interested in dragonflies visits you, which part of the garden would you take him/her to?

[Near the river] [Middle of the garden away from water] [No idea]
[Near the pond] [A combination of these places]

8.Which time of the year are you more likely to find dragonflies in the garden?

[Spring] [Summer] [Autumn] [Winter] [No idea]

9.Would you be interested in learning more about dragonflies?

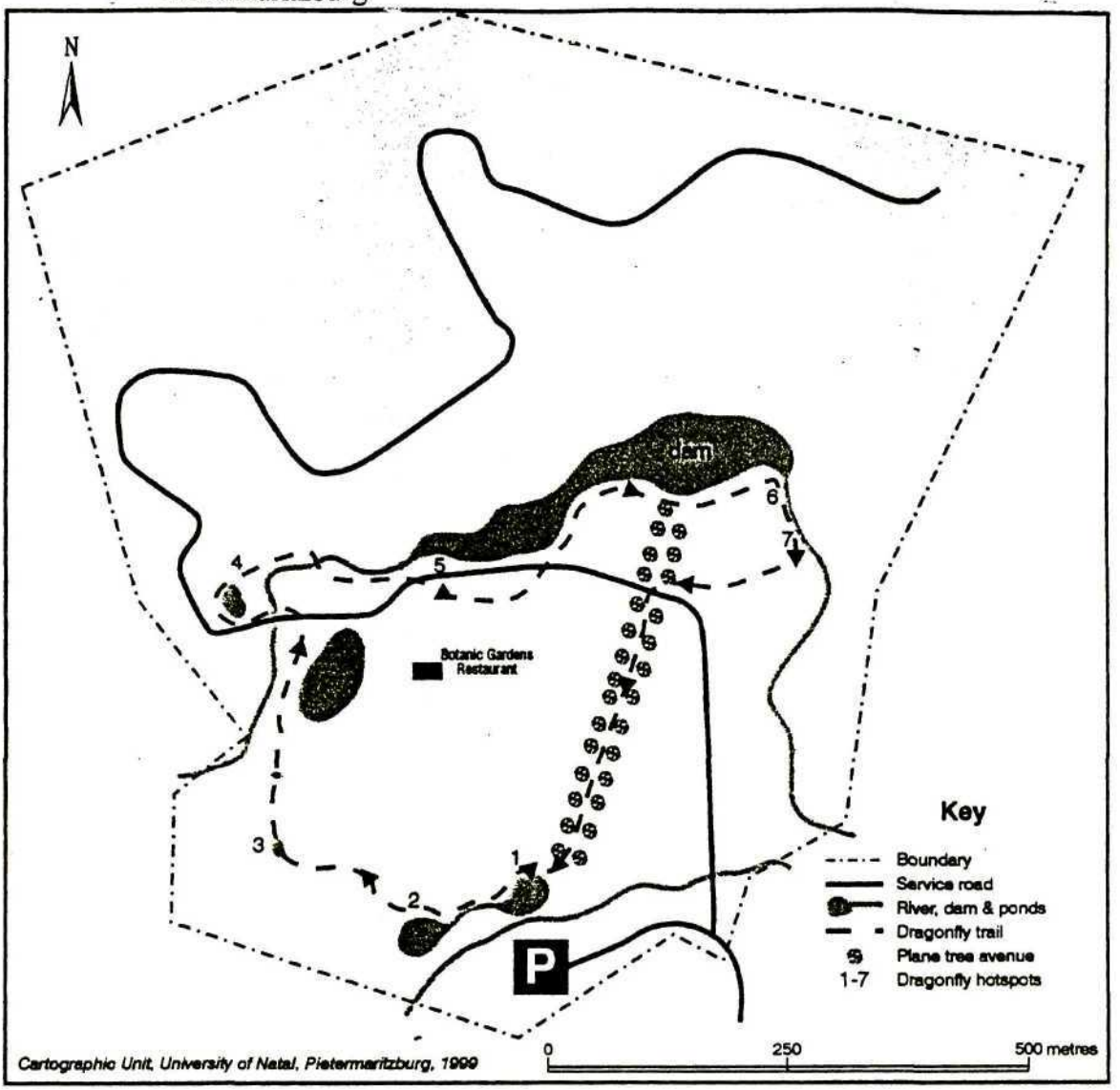
[Yes, definitely] [Yes, possibly] [No]

10.Would you follow a dragonfly trail around the garden?
[Yes, definitely] [Yes, if it is short] [No]

11. Which of the following about dragonflies would you find useful?
[Leaflets] [Guides] [Posters] [Photographs] [Slides]

12. Would you be interested in purchasing your choice in 11 above?
[Yes, definitely] [Yes, possibly] [No]

Appendix 11. Final design for the dragonfly trail and hotspots in the National Botanical Gardens, Pietermaritzburg



Appendix 12. Recommendations for information boards at each of the seven dragonfly hotspots.

Hotspot 1

Biotope description: Open permanent pond with floating lilies and marginal vegetation comprising of reeds, grasses and herbs.

Characteristic species: *P. massaicum, I. senegalensis, C. erythraea, P. flavescens*

Hotspot 2

Biotope description: Shaded semi-permanent pond with a stream outlet located in a forested patch of the gardens with ferns, overhanging macrophytes, trees and marginal vegetation.

Characteristic species: *A. leucosticta, C. tessellatus, O. julia, N. jonesi*

Hotspot 3

Biotope description: Ornamental pond for demonstrative purposes. Vegetation comprises of floating lilies and a variety of marginal weeds.

Characteristic species: *P. lucia, O. julia, E. glaucum, C. glabrum*

Hotspot 4

Biotope description: Open, semi-permanent pond with floating lilies and a variety of aquatic weeds, sedges and rushes.

Characteristic species: *E. glaucum, L. plagiatus, T. stictica, T. arteriosa*

Hotspot 5

Biotope description: Dam and adjoining marshland with submerged aquatic, marginal vegetation and a bordering forest.

Characteristic species: *P. massaicum, E. glaucum, A. speratus, A. imperator*

Hotspot 6

Biotope description: 2.5m high waterfall with forested and grassy banks. Exposed rocks and spillway from the dam.

Characteristic species: *A. falcifera, P. kersteni, P. cognatus, Z. natalensis*

Hotspot 7

Biotope description: Meandering river with grassy, herbaceous and forested banks. Exposed rock also present.

Characteristic species: *P. hageni, P. caligata, T. dorsali Z. natalensis*