Pond biodiversity in a sugarcane-forestry mosaic in KZN

by

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Overall summary

The wetlands of South Africa are threatened by dam creation, agricultural practices and urbanisation. Farm ponds within these wetlands act as habitat islands and are known to support heterogeneous communities of aquatic organisms which often include rare or unique species not found in other water body types. The timber and sugarcane industries of KwaZulu-Natal (KZN) province, South Africa, are very important to the local economy and make up a large portion of the farmland in the province. Timber, and more recently, sugar farmers in KZN are farming their lands with environmental sustainability in mind. This shift towards more biodiversity friendly agriculture should have positive effects on biodiversity conservation. This study aims to assess the differences in species assemblages of three different taxonomic groups within ponds found in forestry and sugarcane agriculture, and to look at the quality of habitat within the two agricultural mosaics using bioindicators. Sites within protected areas were used as benchmark sites.

In Chapter 2, I assessed the conservation value of farm ponds within timber and sugarcane plantations by gathering biodiversity data on plants, aquatic Coleoptera and Odonata. Plants were sampled using transects, aquatic Coleoptera were sampled by sweeping a net through the aquatic area along the banks of the ponds and Odonata were sampled through visual observations. No significant differences were found between the wetland groups regarding species richness of plants, aquatic Coleoptera and Odonata. Species richness of the Coleoptera was low at all sites whilst the species richness of Odonata was highest in sugarcane sites which had a large open water surface, compared to smaller sites within sugarcane and forestry agriculture. Sugarcane sites contained the most invasive alien plants based on high levels of agricultural disturbance whilst still maintaining high levels of Odonata diversity, therefore indicating the importance they possess as alternative habitat for various invertebrates.

In Chapter 3, the focus was primarily on utilising the Dragonfly Biotic Index (DBI) and the presences of rare and threatened Odonata to assess the conservation significance of ponds and reservoirs in a sugarcane-forestry mosaic. In order to achieve this I used the Odonata population data that was gathered, and assigned the various species their scores which subsequently allowed me to make deductions about the habitats in which they were found. The results indicate that the protected areas in my overall study area had the highest quality habitat with more Odonata species which are sensitive to disturbance being found at these localities. Despite this finding, ponds within sugarcane agricultural mosaics were able to support many Odonata

species, including some which were not found in the protected areas. However, these were predominately widespread generalists with low conservation value.

In conclusion, I found that species richness was a poor indication of pond conservation value and subsequently recommend using DBI for future monitoring. Although the sugarcane farms were able to support high numbers of generalist species, these results indicate that farmers could be doing more to encourage environmentally sensitive species into their wetlands, such as restoration through alien clearing.

Algehele samevatting

Die vleilande van Suid-Afrika word bedreig deur damskepping, landboupraktyke en verstedeliking. Plaasdamme binne hierdie vleilande funksioneer soos habitat eilande en ondersteun dikwels heterogene gemeenskappe van akwatiese organismes wat gereeld seldsame of unieke spesies insluit wat nie in ander soorte watermassas voorkom nie. Die bosbou en suikerriet nywerhede van KwaZulu-Natal (KZN) is baie belangrik vir die plaaslike ekonomie en beslaan 'n groot gedeelte van die landbougrond in die provinsie. Bosbou, en meer onlangs, suikerboere in KZN boer hul lande met omgewingsvolhoubaarheid in gedagte. Hierdie verskuiwing na meer biodiversiteits-vriendelike landbou behoort 'n positiewe uitwerking op die bewaring van biodiversiteit te hê. Die doel van hierdie studie was om die verskille in spesiesversamelings van drie verskillende taksonomiese groepe binne damme in bosbou- en suikerrietlandbou te evalueer, en om te kyk na die gehalte van die habitatte in die twee landboumosaïeke met behulp van bioindikatore. Liggings binne beskermde gebiede is gebruik as maatstaf liggings.

In Hoofstuk 2, beoordeel ek die bewaringswaarde van plaasdamme binne bosbou- en suikerrietplantasies deur die insameling van biodiversiteitdata op plante, akwatiese Coleoptera en Odonata. Plantopnames is gemaak met behulp van transekte, akwatiese Coleoptera is versamel deur 'n net te vee deur die water langs die oewer van die dam en Odonata opnames is gemaak deur visuele waarnemings. Geen beduidende verskille is gevind tussen die vleiland groepe ten opsigte van spesierykheid van plante, akwatiese Coleoptera en Odonata nie. Spesierykheid van die Coleoptera was laag by alle liggings, terwyl die spesierykheid van Odonata die hoogste was in suikerrietliggings wat 'n groot oop water oppervlak het, in vergelyking met kleiner liggings binne suikerriet- en bosboulandbou. Suikerrietliggings bevat die meeste indringerplante gebaseer op die hoë vlakke van landbouversteuring, terwyl dit nog steeds hoë vlakke van Odonata diversiteit handhaaf, wat dus hulle belangrikheid as alternatiewe habitat vir verskillende invertebrate aandui.

In Hoofstuk 3, was die fokus hoofsaaklik op die gebruik van die naaldekoker biotiese indeks (DBI) en die voorkoms van skaars en bedreigde naaldekokers en waterjuffers om die bewaringswaarde van damme en reservoirs in 'n suikerriet-bosbou mosaïek te evalueer. Om dit te bereik het ek die Odonata bevolkingsdata wat versamel is gebruik, en DBI tellings toegeken aan die verskillende spesies, wat my toegelaat het om afleidings te maak oor die habitatte waarin hulle voorkom. Die resultate dui daarop dat die beskermde gebiede in my algehele

studie area die hoogste gehalte habitat het met meer Odonata spesies wat sensitief is vir versteuring wat gevind word by hierdie plekke. Ten spyte van hierdie bevinding, was damme binne suikerrietlandbou mosaïeke in staat om baie naaldekoker spesies, insluitend 'n paar wat nie gevind word in die beskermde gebiede nie, te ondersteun. Dit was hoofsaaklik wydverspreide generaliste met 'n lae bewaringswaarde.

Ten slotte, ek het gevind dat spesierykheid 'n swak aanduiding was van dam bewaringswaarde en dus beveel die gebruik van die DBI aan vir toekomstige monitering. Hoewel die suikerrietplase in staat was om groot getalle generiese spesies te ondersteun, dui hierdie resultate daarop dat boere meer kan doen om omgewingsensitiewe spesies aan te moedig in hul vleilande, soos restorasie deur middel van die verwydering van uitheemse plante.

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Table of Contents

Chapter 1

General Introduction: Conserving biodiversity within agricultural mosaics

Agriculture and biodiversity

Agriculture may be defined as the management of terrestrial ecosystems to support the needs of humans through alteration of the land use (Millennium Ecosystem Assessment 2005). A conflict exists however, between agricultural practices and biodiversity maintenance (Firbank *et al*. 2008). As agricultural activity intensifies towards monocultures it can be expected that the natural environment will suffer to some degree and as a result, that biodiversity will be negatively affected (Chamberlain *et al*. 2000). Accordingly, the loss of biodiversity is primarily attributed to the increased intensity of agricultural practices on a global scale (MA 2003; Altieri and Nicholls 2004). Strategic agricultural practices are essential for maintaining biodiversity. This includes the preservation of large areas of natural habitat, particularly in biodiversity hotspots such as the Cape Floristic Region or the Maputaland–Pondoland–Albany Hotspot (Mittermeier *et al*. 2004; Firbank *et al*. 2008). Strategic practices can have significant effects on production through reducing the land requirement for agriculture by increasing the productivity per unit area rather than using less intensive farming methods. This means that less land can be used to produce the same amount of crop, conserving more natural areas (Green *et al*. 2005).

In 2010, the Convention on Biological Diversity met in Aichi, Japan, and developed a set of goals known as the 'Aichi Targets' which aim to increase international efforts at halting environmental degradation (CBD 2011). These targets are encompassed within five overall strategic goals: (1) address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society, (2) reduce direct pressures on biodiversity and promote sustainable use, (3) improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity, (4) enhance the benefits to all from biodiversity and ecosystem services, and (5) enhance implementation through participatory planning, knowledge management and capacity building (CBD 2011). Each strategic goal contains a number of targets which will be used to achieve the respective goal with a total of 20 Aichi Targets (CBD 2011). Some of these targets are directly affiliated to agriculture, freshwater management and, of course, biodiversity conservation which are all key areas that are focused on in this study.

The development of sustainable production landscapes in South Africa

In South Africa, and particularly the KwaZulu-Natal (KZN) province, timber and sugarcane agriculture are important to the local economy (SASA 2015a). The study sites occurred in these agriculture types as sugarcane farming and forestry are the primary agricultural activities in the south Midlands area of KZN. The demand for timber is increasing worldwide which has resulted in more plantations being created, where a natural scenario may have previously existed, in an attempt to supply this demand (Cubbage *et al*. 2010). Timber plantations are often considered by some to contribute little to the biodiversity of a particular area and are largely viewed as a threat to natural systems, particularly in cases when alien species such as *Eucalyptus* are planted (Armstrong and van Hensbergen 1994; Pryke and Samways 2009, Bremer and Farley 2010). Timber plantations within South Africa occupy 1.8 million hectares of land which is about 1.5% of the surface area of the country (DWAF 2006). The large majority of timber plantations are comprised of *Eucalyptus*, *Pinus* and *Acacia* species which are alien to southern Africa (Kirkman and Pott 2002). Not all plantation areas are planted to trees. On average about a third of these plantations are left in their natural state, forming corridors that include nodes and natural landscape features, particularly hilltops and wetlands (Kirkman and Pott 2002; Samways 2007ab).

During the 1990's, forestry companies in Europe implemented a certification system that would allow them to market their product as biodiversity-friendly in response to consumers who were seeking environmentally sound products (Samways *et al*. 2010). Mondi (Pty) Ltd and Sappi (Pty) Ltd, the largest private forestry enterprises in South Africa, were the first to implement the ISO 14001 or FSC (Forestry Stewardship Council) international standards, which was accomplished by 1995 (Kirkman and Pott 2002). The FSC is a non-profit, stakeholder-owned organisation which allows relevant private companies to conduct the FSC certification process on sustainable forestry and annual audits (FSC 1996). According to the Department of Water Affairs and Fisheries (DWAF) (2006), forestry is the most regulated land use in South Africa as DWAF is, at least partly, involved in the management of the plantations, thereby increasing the likelihood that these areas will be managed cognoscente of environmental sustainability. Nevertheless, forestry still adds ecological pressures on the landscape such as changes in soil chemistry and groundwater depletion which aggravates already stressed environments (Armstrong and van Hensbergen 1996). Timber plantations are also known to have a 'hard edge' when alongside indigenous grasslands, and can therefore have detrimental effects on taxa such as butterflies (Lepidoptera) (Pryke and Samways 2001) and grasshoppers (Orthoptera) (Samways and Moore 1991).

The sugar industry in South Africa has yet to implement strict rules on biodiversity friendly farming techniques. Recently some sugarcane farmers in KZN have started using a Sustainable Sugarcane Farm Management System (SUSFARMS ®) which is a system that has been designed and which advocates sustainable sugarcane growing by implementing better management practices (BMPs) (Maher 2007). These BMPs aim to minimise the damage that sugarcane agriculture, and agriculture in general, is causing to the environment (Maher 2007).

Push-pull in the KwaZulu-Natal sugar industry

Conservation in any form can only be effective if there are enough people who are willing to perform the measures which are required (Harrison and Burgess 2000). In order for at least semi-natural areas to survive in the agricultural mosaic it is important for farmers to implement at least some form of biological control strategy which will reduce the reliance on agrochemicals for a pest-free crop (Altieri and Nicholls 2004). An example of such a strategy is the push-pull component in the integrated pest management (IPM) system which controls *Eldana saccharina* Walker (Lepidoptera: Pyralidae), a major pest of sugar. This system uses repellent grasses ((*Melinis minutiflora* P. Beauv (Cyperales: Poaceae)) as well as attractant plants such as *Cyperus dives* Delile (Cyperales: Poaceae) to entice *E. saccharina* out of agricultural fields into more naturalized areas (Conlong and Rutherford 2009; Rutherford and Conlong 2010). The repellent grass is planted along the contours of the field whilst *C. dives* may be planted in moist areas at the bottom of fields thereby establishing a somewhat artificial wetland (Conlong and Rutherford 2009; Rutherford and Conlong 2010). This practice is currently taking place sporadically in some sugar farming areas of KZN (particularly in the Wartburg and Eston areas) and is gaining popularity based on its cost effectiveness coupled with the ability of push-pull to reduce *E. saccharina* populations in sugarcane fields (Barker *et al*. 2006).

Ecological networks in production landscapes

Environmental corridors play important roles in connecting habitat patches, as they prevent isolation of patches of natural habitat thereby reducing further loss of habitat (Fahrig 2003). The connectedness between habitat patches may be in the form of an environmental corridor or a direct link (Bennet 1999). Recently, corridors have been viewed in a positive light with regards to biodiversity conservation and have therefore been implemented in the design of agricultural landscapes, as described in Nasi *et al*. (2008) where the linking of remnant natural forest patches in structurally diverse ways helped to mitigate the effects that large-scale plantations had on primates in Sumatra.

The fragmentation of landscapes has become a topic of concern within scientific literature due to the magnitude of its significance on particular populations found in these habitat fragments (e.g. Fahrig 2003). Small populations located in fragmented habitats face the risk of losing genetic diversity, having reduced reproduction rates as well as becoming extinct (Nason and Hamrick 1997). The specific impact on particular species within fragments is however, difficult to assess due to the differences in ecology and behaviour of different assemblages (Nasi *et al*. 2008). Certain species may be edge specialists and therefore benefit from diverse habitats in close proximity to one another whilst others may be so highly dependent on their particular habitat that they may not be able to move over open ground to locate a new suitable habitat patch (Chapman *et al*. 2006; Costa *et al*. 2005; Gonzalez-Solis *et al*. 2001; Meijaard 2005; Newmark 1991).

Corridors require a suitable interior zone which is difficult to conserve, in order to carry out its primary function. This is due to the existence of an area known as the edge zone which can undermine the whole idea of the corridor if the corridor is too narrow (Pryke and Samways 2012). Edge effects are primarily caused by structural changes along the edge boundary (Cadenasso *et al*. 2003; Harper *et al*. 2005), but are also attributed to a change in soil nutrients and moisture (Li *et al*. 2007). Over the course of time other secondary effects such as roads and alien vegetation gradually increases the intensity of the edge effects which eventually allows generalist species to infiltrate, causing a further imbalance in the system (Pinheiro *et al*. 2010; Ivanov and Keiper 2010; Pryke and Samways 2012). A primary function which corridors perform between fragments is to assist species in getting from one patch to another patch of habitat. However it may also act as a barrier for some species (Samways *et al*. 2010).

The complexity of the biological world cannot be underestimated and accordingly no single corridor will essentially benefit all ecological groups and natural ecological functions (Samways *et al*. 2010). If these corridors are suitably maintained (i.e. alien plant removal), generalist as well as specialist endemic species may reappear in these habitats (Samways and Sharratt 2010; Samways and Pryke 2015). Corridors may also be viewed as 'negative' as they are known to act as pathways for pathogens, predators as well as alien species (Samways *et al*.

2010). In order to create a positive environment for all species one may establish a network of corridors, complete with nodes when they interconnect, which should also include different ecosystems (such as wetlands) and physical landscape features (such as hilltops) (Samways *et al*. 2010). This interconnected network of corridors is known as an Ecological Network and has proven to be an effective means of biodiversity conservation, provided the corridors are at least 250 meters wide, as shown by previous research (Samways *et al*. 2010; Samways and Pryke 2015).

South Africa's natural and artificial water reservoirs

South Africa may be classed as a semi-arid country. However, there are extreme changes in annual rainfall from the western to the eastern parts of the country. Areas within the Northern Cape Province can experience annual rainfall between 100 mm and 200 mm whilst areas on the east coast may see rainfall in excess of 1000 mm annually (Wessels *et al*. 2007). The El Niño-Southern Oscillation (ENSO) weather event has a profound effect on local weather within southern Africa causing much variability in precipitation, occasionally leading to times of periodic drought in the country (Anyamba *et al*. 2002; Wessels *et al*. 2007). The reservoirs or ponds which are constructed for agricultural purposes act as a refuge habitat for a wide range of aquatic species which would have formerly occurred naturally in the untransformed wetland or riverine areas (Casas *et al*. 2011; Takamura 2012). However, the changing of natural land-use to an agricultural initiative results in non-point pollution caused by run-off and seepage among other factors, as well as loss of naturalised habitat (Usio *et al*. 2013).

In the plantations of KZN, agriculture is often very intensive. However, farmers are generally respectful of wetlands and accordingly have designated environmental corridors, along wet zones of their land that encompass semi-natural settings such as wetlands, streams, reservoirs and ponds. Ponds are found in many environments and frequently account for a high percentage of freshwater biodiversity at a regional level (Williams *et al*. 2003; Scheffer *et al*. 2006). A high proportion of these pools are seasonal, meaning they have a fluctuating water level, which leads to a variety of temporary water fauna inhabiting these ponds (Bilton *et al*. 2008). Recently, temporary ponds have been increasingly recognised as an important habitat zone for certain plant and animal species. However, there are only a handful of studies which have been completed that look specifically at the conservation status and biodiversity of this specialist habitat type (Barr *et al*. 1994; Collinson *et al*. 1995; Williams *et al*. 2001; Nicolet *et* *al*. 2004). These temporary ponds essentially act as habitat islands for aquatic plants and macroinvertebrates found within the natural landscape (Bilton *et al*. 2001). This can also be related to wetlands and other water bodies located within an agricultural mosaic within the exception that these bodies are severely threatened by a variety of agriculture-related activities.

In a study completed by Rouget *et al*. (2003), the overwhelming conclusion was that there are currently three main threats to biodiversity in the Cape Floristic Region (CFR) namely (1) increased intensity of agriculture, (2) urbanisation and (3) the impact of alien plants. Water bodies throughout KZN are also under threat from these three different avenues of disturbance therefore further research is required into the impacts they are having. The role that these waterbodies perform regarding the conservation of various animal and plant assemblages, particularly in agricultural areas, cannot be underestimated.

Bioassessments of water bodies for water quality and biodiversity value

In order to assess the conservation value of various ecosystems such as wetlands or ponds, thorough surveys and subsequent long term monitoring programs need to be completed to determine species richness patterns (Briers and Biggs, 2003). Specific sites may be granted conservation value status due to factors such as rarity of present species or high species richness. However, it has become common practice for researchers to focus on specific taxa for the bioassessment process including, but not limited to, Odonata (Odonata is used to represent both of the dragonfly sub-orders: Anisoptera and Zygoptera, unless explicitly stated otherwise) (e.g. Simaika and Samways 2012) and Coleoptera (e.g. Foster *et al*. 1989). It is true that no single species can act as a perfect representative for all other species present in an area. However, certain criteria for the selection of surrogate species have been described (e.g. Pearson 1994), which has subsequently led to the selection of Odonata and Coleoptera as suitable indicator taxa. There are several surrogate selection criteria which are used to increase the generality of the indicator organism, these are: (i) taxonomically sound and stable populations; (ii) biology and life cycle well understood and studied; (iii) populations are relatively easy to survey i.e. survey can be completed by inexperienced parties; (iv) the concerned order, family, tribe or genus must occur over a wide geographical range and within variable habitat types; (v) at species or subspecies level, specialisation of certain populations should increase their sensitivity to habitat alteration; (vi) some evidence is required to show patterns exhibited by the potential indicator are reflected in other unrelated taxa; and (vii) there must be potential economic importance of the surrogate for the purpose of convincing individuals, within and outside of the scientific realm, that resources should be dedicated to the study and conservation of the surrogate (Noss 1990; Pearson and Cassola 1992).

Each ecosystem is unique in a certain way. Accordingly, the surrogate selection criteria will differ slightly as some criteria become more important than others. Ultimately, almost every study into the biodiversity of an area/region fits within two distinct categories, namely monitoring studies and inventory studies (Pearson 1994). Monitoring studies focus primarily on the change of habitats over time (e.g. Kremen 1992). In this case priority for surrogate choice is placed on the potential surrogates' sensitivity to environmental change whilst in inventory studies priority of surrogate choice is based on a strong phylogenetic and biogeographic history, such as endemism (Erwin, 1991). Inventory studies focus on the distribution of taxa for the purpose of establishing areas of conservation significance (McKenzie *et al*. 1989; Kremen 1994; Pearson 1994). Some surrogates have been the focus of scoring systems, for example Odonata, which have been used to assess freshwater health (Oertli 2008), ecological integrity (e.g. Smith *et al*. 2007; Simaika and Samways 2009) as well as habitat recovery (Samways and Taylor 2004), through an assessment strategy known as the Dragonfly Biotic Index (DBI) (Simaika and Samways 2009). This index is particularly tailored for lotic and lentic systems within South Africa and uses a weighted scoring system based on three sub-indices, namely sensitivity to disturbance, distribution and threat status (i.e. IUCN Red List status)

Aims and outline

The overall aim of this study is to assess the biodiversity value of remnant wetlands, reservoirs and ponds within commercial forestry and sugarcane using three taxa: (1) plants, (2) aquatic Coleoptera and (3) Odonata. My objectives are to compare pond quality and biodiversity between sugarcane and forestry agricultural mosaics, and specifically to look at if biodiversity is different between the two transformed landscapes, as well as which environmental variables are responsible for these differences. I will also compare the pond quality and biodiversity of these transformed landscapes to protected areas, which will act as benchmark sites for this study. In order to accomplish these objectives I will collect biodiversity data from farms and natural areas of the southern KZN midlands, and then acquire crucial information on species richness, abundance and composition of the aforementioned taxa. I will also use the Odonata as an indicator taxon and make deductions on the habitat quality of my agricultural sites based on the DBI.

Chapter 1 of this thesis gives a general introduction of biodiversity within agricultural settings with particular focus on South African agricultural practices. The aims and objectives of the study are also clearly defined in this chapter. Chapter 2 is an in-depth analysis of the population dynamics of the three taxa within agricultural mosaics as well as areas that are natural and protected. This chapter determines whether the conservation of wetlands within agricultural areas is having a positive effect on biodiversity. Chapter 3 is a shorter chapter that looks particularly at Odonata as bioindicators in the study area and subsequently which agricultural mosaic has the best ecological integrity based on the DBI scoring system. Chapter 2 and Chapter 3 are written in the form of a standalone publication and, as a result, some repetition will occur that is unavoidable. In Chapter 4, general conclusions are made about the results of this study and management recommendations are given regarding the conservation of biodiversity in agricultural mosaics. Appendix 1 is focused on stem borer diversity at the wetland areas within the agricultural mosaics.

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Chapter 2

A sugarcane-forestry mosaic maintains local pond biodiversity

Abstract

South African wetlands are threatened by dam creation, agricultural practices and urbanisation. These wetlands are particularly important for the conservation of the biodiversity of natural fauna and flora in agricultural mosaics. In order to assess the conservation value of farm ponds within timber and sugarcane plantations, I compared three taxa from these water bodies against the same three taxa from protected area sites in the same location. Data from plant, Odonata and aquatic Coleoptera assemblages was acquired over two sampling sessions during mid-summer and spring of 2014. Overall species richness of Odonata was highest in sugarcane sites with a large open water surface compared to smaller sites within sugarcane and forestry agriculture. Aquatic Coleoptera species richness was low in all four wetland groups, indicating low overall diversity of this taxon in the area. Sugarcane pond sites contained the most invasive alien plants based on high levels of agricultural disturbance, whilst still maintaining high levels of Odonata diversity, therefore indicating the importance the ponds possess as alternative habitat for various invertebrates. Forestry sites held some species which were not found at any other sites, illustrating their importance. Overall, these agricultural systems represented the natural biodiversity remarkably well, and thus the restoration of wetlands and ponds within sugarcane agriculture and commercial timber production areas is encouraged.

Keywords: Agriculture; Ponds; Odonata; aquatic Coleoptera; Plants; Biodiversity

Introduction

Wetland areas in South Africa have been in a state of neglect for many years and are currently threatened, and often taken for granted as a natural resource (Mlambo *et al*. 2011). The south-Midlands of KwaZulu-Natal (KZN) is an area where natural wetlands are fairly scarce due to intensive agriculture. However, man-made reservoirs and ponds of variable size are scattered throughout the farmlands with their main use being for irrigation as well as for recreation. Begg (1986) showed that a large percentage of naturally occurring wetlands in KZN have been lost due to the damming of rivers as reservoirs, as well as farm pond creation, commercial forestry and urbanisation. These reservoirs, which have been created along historic water courses, are habitat for native insects and plants which would have traditionally occurred in the area prior to the commencement of large scale land-use alteration. The connectivity of these semi-natural areas in the form of environmental corridors, which allow for the dispersal of organisms, is critical for curbing the trend of habitat loss and effects of isolation on habitat patches (Fahrig 2003; Samways *et al*. 2010). Temporary ponds in terrestrial landscapes act as habitat islands for macroinvertebrates as well as aquatic plants (Bilton *et al*. 2008). This could also be the case for the more permanent ponds or reservoirs in an agricultural setting with regards to conserving local insect and plant biodiversity. Farm ponds worldwide are known to support heterogeneous communities of aquatic organisms which often include rare or unique species not found in different water body types, such as streams or rivers in the immediate area (Oertli *et al*. 2002; Williams *et al*. 2004). In spite of the importance of farm pond's provision of habitat to aquatic species, they are under threat from a range of sources including chemical pollution, eutrophication from agricultural runoff, land-use change, physical destruction and invasion by non-native species (Declerck *et al*. 2006; Curado *et al*. 2011; Takamura 2012).

The majority of suitable arable land for timber production is located in Mpumalanga and KZN, with these areas also accounting for the highest rate of afforestation according to the DWAF (2006) report (Samways, *et al*. 2010). Sugarcane on the other hand is found almost exclusively in the coastal wetter regions of KZN with a lesser percentage located inland and in Mpumalanga (Appendix 3 Fig. 4; SASA 2015b). The 1990's saw a shift in consumer demand to products which were created in an environmentally sound manner (i.e. biodiversity and socio-economically friendly) (Samways *et al*. 2010). Recently some sugarcane farmers have begun implementing sustainable farming approaches (known as SUSFARMS ®) which is a set of guidelines which endorses economic, social and environmentally-sustainable farming practices (Maher 2007). SUSFARMS ® includes a focus on wetland and hydrological conservation which is a key area of concern for biodiversity conservation in agricultural landscapes (Maher 2007).

Wetland invertebrates are a poorly studied assemblage despite the fact that they make up a large number of the total wetland animals in a system (Krieger 1992; Batzer and Wissinger 1996; Mlambo *et al*, 2011). Recent interest in wetland invertebrates has become apparent in the scientific community primarily due to their importance as a tool for bioassessment (Mlambo *et al*, 2011). In KZN, very little is known about aquatic invertebrate assemblages. This is also accurate for other areas of the country such as the Cape Floristic Region (CFR) and concerns aquatic invertebrates inhabiting running water and particularly those associated with the standing water bodies (Apinda-Legnouo *et al*. 2013). Wishart and Day (2002) found that the species richness of aquatic invertebrates in South Africa is concentrated in the north eastern parts of the country (e.g. iSimangaliso Wetland Park). Endemism is highest within the CFR underlining the sentiment that these two geographic areas, in particular, require more attention and understanding regarding respective aquatic invertebrate assemblages.

Many studies use Odonata (Insecta: Anisoptera; Insecta: Zygoptera) as indicators of habitat quality and for the assessment of riverine habitats (Simaika and Samways 2009). Fully mature Odonata (Odonata is used to represent both of the dragonfly sub-orders: Anisoptera and Zygoptera, unless explicitly stated otherwise) are known to be sensitive to changes in their immediate habitats whether it is the water or the bank which has been altered (Clark 1991). It is unclear which species will remain after these changes have occurred. However, the physical and physiognomic conditions determine which species will establish themselves at a particular locality (Steytler and Samways 1995; Osborn and Samways 1996). The aquatic system is of particular importance to Odonata in temperate regions due to the extended phase of their existence (1-4 years) which is spent submerged relative to other aquatic insects that spend shorter portions of their existence under water (Remsburg and Turner 2009). The land-water ecotone is an equally important and structurally complex zone that provides crucial habitat to a wide variety of organisms (Decamps *et al*. 2004). The complexity of this zone is created by a combination of factors including abiotic characteristics (substrate, slope, etc.), riparian and littoral vegetation as well as anthropogenic disturbances (bridges, housing, agriculture, etc.) (Hansen *et al*. 2005; Remsburg and Turner 2009). The effects of anthropogenic as well as natural drivers of structural complexity on Odonata assemblages has not been well documented in the past (Remsburg and Turner 2009). Samways (1989) showed that construction of ponds and farm reservoirs increased abundances of generalist Odonata species, whilst Suh and Samways (2005) revealed that local Odonata diversity in Pietermaritzburg more than doubled 13 years after reservoir construction, highlighting the importance of this anthropogenic feature for conserving diversity of Odonata within a disturbed landscape. Furthermore, set-aside land within timber plantations have been shown to protect lentic Odonata when compared to a protected area within Zululand region of KZN (Pryke *et al.* 2015)

Certain aquatic plant species found in KZN have been known to negatively impact biodiversity such as the water hyacinth (*Eichhornia crassipes* (Mart.) Solms (Commelinales: Pontederiaceae)) which is the most problematic alien aquatic plant in South Africa due to its' ability to force native flora and fauna to localized extinction (Coetzee *et al*. 2014). In contrast, wetland plants such as *Cyperus dives* Delile (Cyperales: Cyperaceae), which are indigenous to KZN wetlands, act as natural water filters and as host plants of agricultural pests such as *Eldana saccharina* Walker (Lepidoptera: Pyralidae) (Atkinson 1980). The transformation of traditional rolling grassland into intensive agriculture has a clear effect on local plant diversity. However, the extent of these effects has not been well documented in the study area.

In this chapter, I aim to assess the effectiveness of biodiversity conservation within the respective agricultural mosaics of timber and sugarcane farms, in the south-Midlands area in KZN. In order to achieve this I compared three different taxa (aquatic Coleoptera, Odonata and plants) between reservoir or pond sites on sugar and timber plantations and compared their biodiversity with similar hydrological sites in local protected areas (PAs). The level of congruence between sites within the production landscape compared to those in the natural control areas will allow me to assess the biodiversity importance of ponds in transformed landscapes. These three groups were chosen as they are prevalent in and around the water bodies as well as having indicator properties which assist in determining overall ecosystem health (Heard *et al*. 1986; Smith *et al*. 2007; Simaika and Samways 2009). I hypothesise that an indigenous undisturbed setting would provide refuge to a higher species richness, followed by sites in the timber matrix catchment as these plantations are managed and regulated with environmental sustainability in mind (DWAF 2006).

Materials and methods

Sampling layout

Sampling was conducted on commercial sugar and timber estates, 40 km south-east of Pietermaritzburg, KZN, South Africa (29°56'10.16"S 30°31'31.15"E) ca. 45 km from the coast and an elevational range of 500-900 m.a.s.l. The study area and specific sites are clearly depicted in Appendix 3 (Fig 1.-3.). A total of 40 wetlands were selected as sites in which three taxa (Odonata, Coleoptera and Plantae) were sampled. The 40 total sites comprised ten sites in protected habitat, 20 sites within sugarcane catchments (ten in large ponds and ten in small ponds) and ten sites within forestry catchments (Table 2.1). The sites within the PAs give a baseline of species richness and assemblage composition to which sites within the transformed areas can be compared. The sites in the forestry catchment (FOR) were variable in size, whilst 10 sites within the sugarcane catchment were fairly large and will be described in analyses as BC ('big cane'). Subsequently there were 10 SC ('small cane') sites were relatively small, allowing for a range of data to be collected on water bodies in sugarcane catchments (Table 2.1). All sites were selected based on the general size of the immediate wetland and not just surface water diameter. The study sites, referred to in Table 2.1, were all surrounded by various riparian and aquatic plant types which often included many alien species.

Table 2.1. The different catchment types and sampling times of this study. Refer to Appendix 4 for images of site examples.

Important Factors	Abbreviation	Description
Big cane	BC	BC refers to ponds, reservoirs and overall wetland sites located within a sugarcane agricultural catchment. The water bodies of BC sites were between 50 and 150 m in diameter.
Small cane	SC	SC refers to ponds, reservoirs and overall wetland sites located within a sugarcane agricultural catchment. The water bodies of SC sites were between 3 and 30 m in diameter.
Commercial forestry	FOR	FOR refers to ponds, reservoirs and overall wetland sites located within a forestry agricultural catchment. Forestry sites comprised either *Eucalyptus* or *Acacia* stands. The water bodies of FOR sites were between 3 and 50 m in diameter.
Protected area	PA	PA refers to ponds, reservoirs and overall wetland sites located within a protected/historic catchment with no or minimal agricultural effects. The water bodies of PA sites were between 3 and 150 m in diameter.
Early summer	ES	ES or ‘Early Summer’ refers to the time of the year when sampling was done, in this case, during November and December.
Late summer	LS	LS or ‘Late Summer’ refers to the time of the year in which sampling was done, in this case, between February and April.

Sampling took place during two different seasonal periods during 2014. The first sampling effort took place in the late summer between February and April 2014 (LS) (Table 2.1). During this first period, all three taxa were sampled. The plants were only sampled once as it is unlikely that they would undergo change within a year, especially as the sites had no major disturbances. The second sampling period was in the early summer at the end of November and early December 2014 (ES) (Table 2.1) where data were collected on the local Odonata and aquatic Coleoptera species. In June of 2015, readings of dissolved oxygen and pH were collected from the ponds and reservoirs at all 40 sites to assess the impact of these environmental variables. As the 40 sites were observed twice in 2014, the study comprised a total of 80 site visits.

Odonata sampling

Odonata individuals were counted by walking through and around the specific study sites, stopping at relevant times to identify species using close-focus binoculars (Samways and Sharrat 2010). Observations of Anisoptera and Zygoptera took place over four 20 min sessions (twice per season) to record all species present in the area (Kutcher and Bried 2014). Species that were not easily identified were caught with a net and inspected more closely. In some cases, specimens were preserved and identified in the laboratory. During Odonata sampling, additional environmental variables such as temperature, humidity, wind speed and cloud cover (CC) were also recorded. *Trithemis furva* (Karsch, 1899) (Odonata: Libellulidae) and *T. dorsalis* (Rambur, 1842) (Odonata: Libellulidae), two Odonata species that are virtually indistinguishable in the field, were grouped together as a morphospecies complex during initial fieldwork. However, after firm identification it became clear that the morphospecies was most likely *T. furva*, also supported by known distribution and elevation records (Samways 2008). Odonata sampling took place on warm days with minimal cloud cover, between 11h00 and 15h00, which was deemed to be an appropriate set of conditions as this is when adult Odonata are most active therefore giving a comprehensive sample of Odonata species present at a given site (Samways and Sharratt 2010).

Aquatic Coleoptera sampling

Sampling of aquatic Coleoptera followed standardised techniques utilised by Apinda-Legnouo *et al*. (2013). Accordingly, quadrats were set out along the banks of water bodies which were

5 m in length and 2 m in diameter. The 2 m diameter was wide enough to extend just past the edge of the plant bank. Sampling was completed by sweeping the immediate aquatic area with an aquatic net for a total time of 45 min per site (as this was when Apinda-Legnouo *et al*. (2013) acquired a sufficient representation of species richness). I performed the sweeping activity at three plots within each site for a time of 15 min, thereby accounting for different micro habitats at each site. This sampling was done only at the edge of the various water bodies to a maximum depth of 1 m as this is where most aquatic insect life occurs in this area (Samways *et al*. 1996). In the field, all aquatic Coleoptera were retained and preserved for later identification. All species of aquatic Coleoptera were initially sorted to morphospecies and then were more accurately identified to genus level using Stals and de Moor (2007). There was often a substantial amount of bycatch, primarily in the form of Hemiptera, Plecoptera, Ephemoptera, and Odonata. Although these groups were not pertinent to the study, their general abundance in comparison to the aquatic Coleoptera was noted.

Plants

The assessment of plant communities within the study sites was completed at the end of the first sample period. Transects were set up at each particular site and were 100 m long. At 1 m intervals along each transect plant density, plant height and plant species were recorded. The density and height was measured with a measuring pole. The amount of times any plant touched the measuring pole, when the pole was placed vertically at an interval, was recorded to give an indication of the density of plant cover at the wetland. The specific plant that was in contact with the measuring pole at the intervals was recorded as the plant species of that point. The height of the plant was measured by placing the measuring pole alongside the specific plant.

To account for plant species richness, a sample was taken of each species that was discovered in the field and arranged into a morphospecies catalogue that was used during fieldwork. Each plant sample was flattened in a plant press which, upon completion of the fieldwork, was then sent to the South African Sugarcane Research Institution (SASRI) for positive identification of the samples. I also had assistance from Mrs Suzaan Kritzinger-Klopper of Stellenbosch University with plant identification. Certain easily identifiable species were identified in the laboratory with the help of literature such as van Oudtshoorn (2002).

Environmental variables

Environmental variables included here were pH using a testo 206-pH1 hand held meter, and dissolved oxygen using a Hanna HI 9142 dissolved oxygen meter. Air temperature, humidity and wind speed were recorded using a Kestrel 4000 Pocket Weather Tracker (Table 2.2). Other site variables recorded were elevation, proximity to agriculture (PROX) and water body diameter (DIAM) which were calculated using Google Earth. Finally the following were visually estimated using site photographs: % macrophyte cover (MAC), % sedge cover, % bulrush cover, % long grass (LG) cover and cloud cover (CC) (Table. 2.2).

Table 2.2. Relevant environmental variables included in the study accompanied by assigned abbreviations and measurement units. Certain values had to be inserted into distinct categories (categorized values) for use in PRIMER 6.

Environmental variables (EV's)	Abbreviations	Measurement unit	Categorized values		
			High	Medium	Low
pH	pH	pH	x>8	7.5>x>8	x<7.5
Dissolved oxygen	DO_2	Parts per million (PPM)	x>11	9>x>11	x<9
Air temperature	none	°C	n/a	n/a	n/a
Humidity	none	Percentage	n/a	n/a	n/a
Cloud cover	CC	Okta (eighths)	n/a	n/a	n/a
Wind speed	WS	Km/h	n/a	n/a	n/a
Elevation	none	Meters above sea level (m.a.s.l.)	n/a	n/a	n/a
Proximity to crops/agriculture	PROX	Meters	x>60	20>x>60	x<20
Diameter of wetland	DIAM	Meters	x>60	20>x>60	x<20
% overall macrophyte cover	MAC	Percentage	x>75	40>x>75	x<40
% sedge cover	none	Percentage	x>75	40>x>75	x<40
% bulrush cover	none	Percentage	x>75	40>x>75	x<40
% long grass cover	LG	Percentage	x>75	40>x>75	x<40

Statistical analyses

Data were shown to best fit a Poisson distribution leading to choice of generalised mixed linear models (GLMM) fit by a Laplace approximation and with a Poisson distribution for analysis (Bolker *et al*. 2009). Models were created for species richness for plants, species richness and abundance for aquatic Coleoptera and species richness and abundance for Odonata in R (R Development Core Team 2013) using the *lme4* package (Bates and Sarkar 2007). These models were built with wetland type, pH, DO_2, DIAM, PROX, MAC, % sedge cover, %

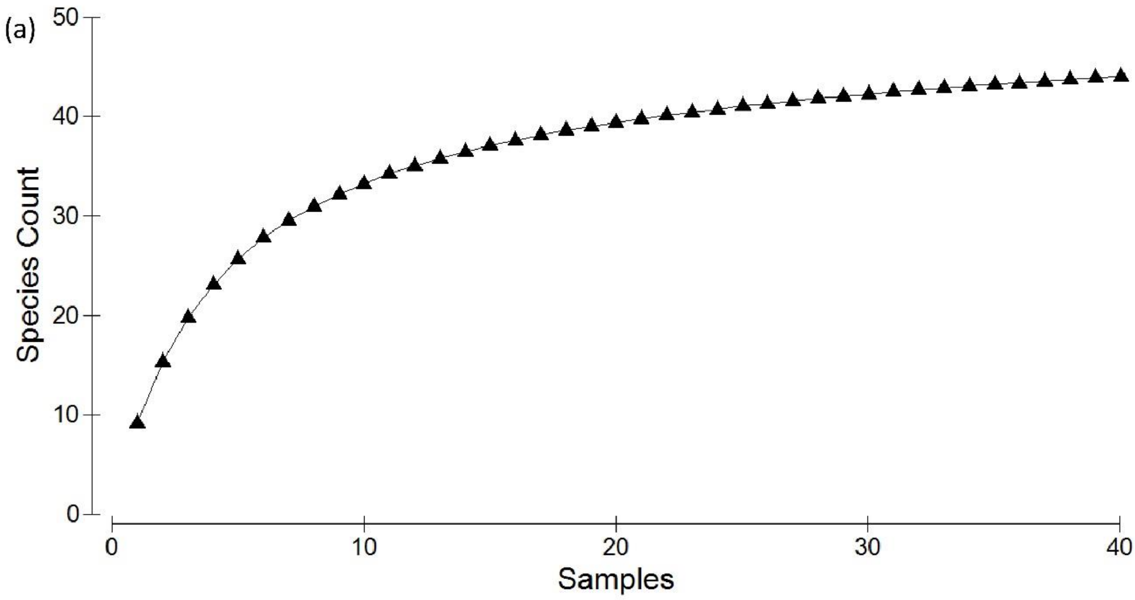
bulrush cover, % LG cover, air temperature, humidity, CC and wind speed as fixed variables and elevation and season as random variables. Further analyses on post-hoc analyses were performed on the water body type using a Tukey post-hoc test in the R package *multcomp* (Hothorn *et al*. 2008).

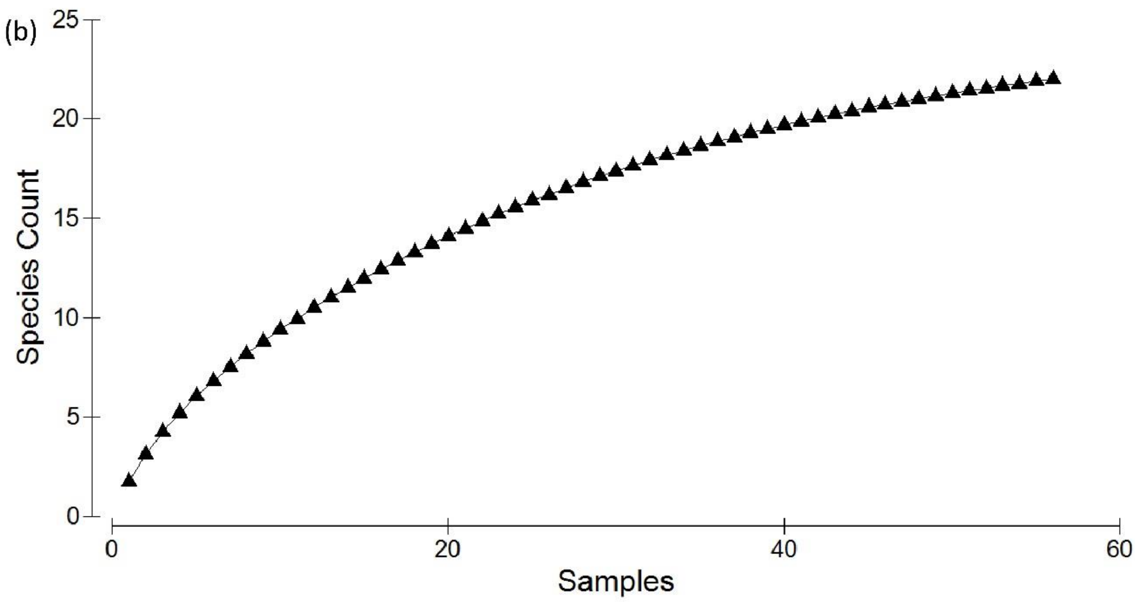
To determine the differences in the species composition of the three taxonomic groups, I made use of Permutational multivariate analyses of variance (PERMANOVA) in PRIMER 6 (PRIMER-E, 2008). By using the PERMANOVA I was able to compute pseudo-F and p-values as well as pairwise differences within tests. 9999 permutations were used to evaluate changes based on sampling season as well as wetland type. Analyses were then performed with the use of Bray-Curtis similarity measures which assesses species composition based on abundance data of particular species (Anderson 2001). Species accumulation curves and non-parametric estimators Chao2 and Jacknife2 were also used to assess adequateness of sampling (PRIMER-E, 2008).

Results

Species richness

A total of 3912 aquatic and terrestrial plants were sampled on 40 transects in and around the wetland sites of the study, and included a total of eight orders. Overall results showed that the order Poales dominated the sites (75.15%), whilst other fairly prominent orders included Rosales (7.90%) and Asterales (5.73%). Plant orders which were in the minority included Polypodiales (3.60%), Salviniales (2.63%), Lamiales (1.92%), Asparagales (1.02%), Fabales (0.82%), Caryophyllales (0.74%) and Polygonales (0.49%). *Typha capensis (Rohrb.) N.E. Br* (Poales: Typhaceae) was the most sampled individual species making up 9.82% of the total plant inventory. A total of 44 species were recorded. The species accumulation curve for the plant species was flattened off after the 40th species indicating adequate sampling for the study area (S_{obs} = 44, Chao2 = 48.5±4.8, Jacknife2 = 51.85; Fig.2.1c).


(a)
Species Count
Samples
0
10
20
30
40
50


(b)
Species Count
Samples
0
5
10
15
20
25
40
60

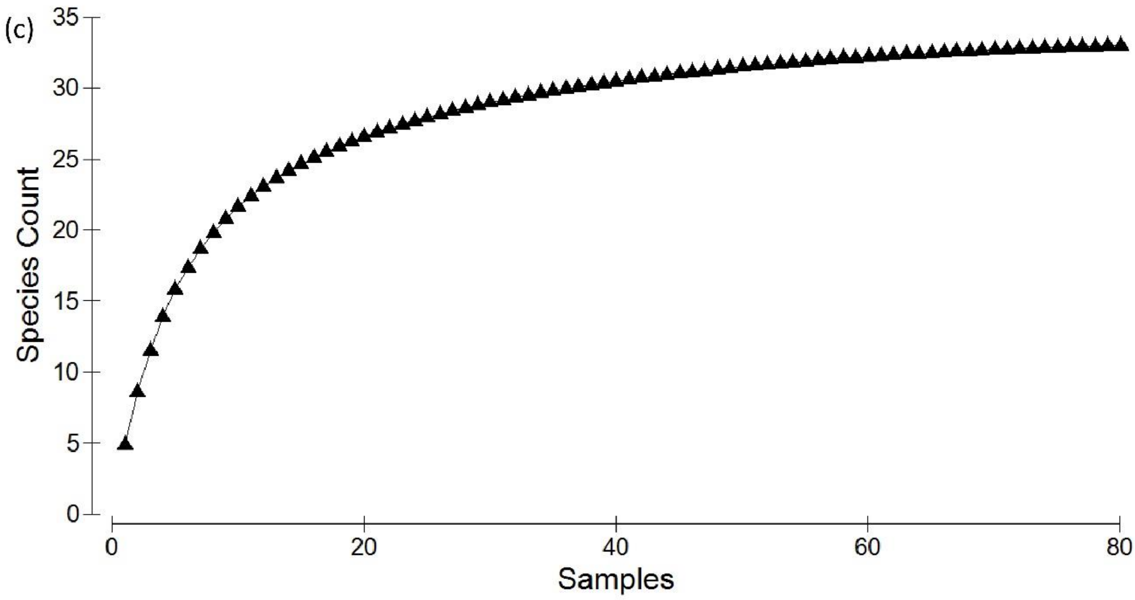


Figure 2.1. Species accumulation curves showing the total species collected at the sites. Plant specimens were only collected over 40 sites (a), while aquatic Coleoptera specimens were sampled at 80 sites (both seasons). However, they were not found at every site (b). Odonata specimens were also recorded at all 80 sites (c). A full species list is available in Appendix 2.

All plant species which were sampled in the wetland sites were either Least Concern (LC) or Not Evaluated (NE) according to the SANBI Red List of South African Plants (SANBI 2015).

GLMMs showed no single environmental variable had a significant impact on overall plant species richness (Table 2.3). A Tukey test revealed no significant differences in plant species richness between the four wetland groups (Table 2.5). However, the wetland sites in FOR showed slightly higher plant species richness than the other three catchments (Fig. 2.2a). The PA sites were the least invaded of all four catchments (seven non-natives recorded) whilst the BC and SC sites were the most invaded (13 non-natives recorded, respectively). FOR sites had a total of 11 non-native plant species.

Table 2.3. Species richness results from generalized linear mixed models analyzing the response of plants, aquatic Coleoptera and Odonata to various environmental variables. Values represent chi-squared (χ^2) values, while bold χ^2 values indicate a significant p-value, * < 0.05, ** <0.01, ***< 0.001.

Major Factor	**Taxa**	**Variables**	**Overall**	**ES**	**LS**
Species Richness	**Plants**	Type	3.0626		
		pH	1.5664		
		DO2	1.5664		
		DIAM	0.3524		
		PROX	0.0437		
	Aquatic Coleoptera	Type	6.3109	5.9018	1.4855
		pH	0.0382	0.0297	0.0007
		DO2	0.8687	1.5615	0.02
		DIAM	0.1651	0.0768	0.5159
		PROX	0.0302	0.2377	0.0007
		MAC	0.1057	0.005	0.0917
		%Sedge	0.0754	0.0042	0.0628
		%Bulrush	0.0595	0.0012	0.0581
		%LG	0.1659	0.0224	0.3126
	Odonata	Type	1.0995	0.2689	1.2865
		pH	2.387	0.9037	**3.8553***
		DO2	0.7812	0.628	1.1035
		DIAM	0.5177	0.0221	1.8847
		PROX	0.4171	0.2421	1.1148
		MAC	0.1326	0.006	1.5514
		%Sedge	0.0919	0.0253	1.5609
		%Bulrush	0.1756	0.0039	1.6735
		%LG	0.1613	0.1845	0.4031
		Temp	0.0943	0.3973	2.2232
		Humid	0.0052	0.0936	3.0894
		CC	6.0741	2.6226	4.2363
		WS	1.4387	1.9838	0.0062

Table 2.4. Abundance results from generalized linear mixed models analyzing the response of aquatic Coleoptera and Odonata to various environmental variables. Values represent chi-squared (χ^2) values, while bold χ^2 values indicate a significant p-value, * < 0.05, ** <0.01, ***< 0.001.

Major Factor	Taxa	Variables	Overall	ES	LS
Abundance	**Aquatic Coleoptera**	Type	**11.458****	7.7166	**16.219****
		pH	**4.6***	3.2457	2.0492
		DO2	1.7637	2.7419	0.001
		DIAM	1.2833	2.2995	1.4008
		PROX	1.0813	1.456	1.1471
		MAC	3.7996	0.0671	**6.5097***
		%Sedge	3.3915	0.004	**7.2777****
		%Bulrush	3.2731	0.0069	**6.9961****
		%LG	2.9277	**9.2605****	2.266
	Odonata	Type	6.5572	6.7126	**8.462***
		pH	2.6758	0.6048	**5.1228***
		DO2	0.0425	1.2894	0.7154
		DIAM	0.1522	0.1814	1.7102
		PROX	1.2695	**8.768****	3.355
		MAC	0.1165	0.0151	0.3338
		%Sedge	0.1444	0.0119	0.4173
		%Bulrush	0.0638	0.0003	0.5322
		%LG	0.0505	0.2734	1.2709
		Temp	0.8999	0.0024	**9.2388****
		Humid	1.1003	1.8404	**6.5493***
		CC	**14.032***	**17.011****	6.7179
		WS	**9.5619****	**15.622*****	0.0548

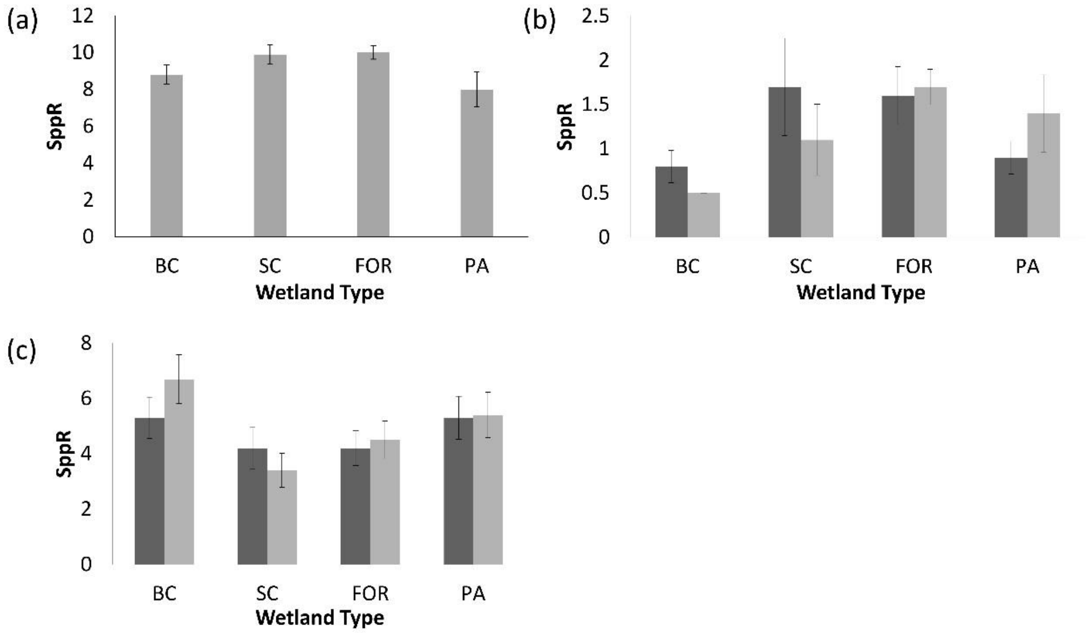


Figure 2.2. Species richness of the three focal taxa at the different wetland types sampled (Mean ± Standard error). The darker bars represent early season (ES) sampling whilst the lighter bars indicate late season (LS) sampling. Plant species richness is only shown for LS (a) whilst aquatic Coleoptera species richness (b) and Odonata species richness (c) occurred over both sampling seasons(BC = Big Cane, SC = Small Cane, FOR = Forestry and PA = Protected Areas).

Table 2.5. Tukey pairwise test tables from GLMM data comparing different wetlands with regards to species richness. Overall values are given along with ES and LS values. Bold z-values indicate a significant p-value, * < 0.05, ** < 0.01, *** < 0.001.

	Species richness						
	Plants	**Aquatic Coleoptera**			**Odonata**		
Wetland Comparisons	**Overall**	**Overall**	**ES**	**LS**	**Overall**	**ES**	**LS**
FOR - BC	1.064	2.225	2.24	0.8	-1.035	0.156	-1.019
PA - BC	-0.436	1.678	1.353	1.001	-0.306	-0.335	-0.408
SC - BC	1.234	2.019	1.748	0.992	-0.598	-0.139	-0.113
PA - FOR	-1.142	-0.051	-0.338	0.422	0.333	-0.486	0.169
SC - FOR	-0.055	-0.536	-0.824	0.139	0.36	-0.319	0.818
SC - PA	1.082	-0.299	-0.206	-0.318	-0.096	0.292	0.374

Table 2.6. Tukey pairwise test tables from GLMM data comparing different wetlands with regards to abundance. Overall values are given along with ES and LS values. Bold z- values indicate a significant p-value, * < 0.05, ** < 0.01, *** < 0.001.

	Abundance					
	Aquatic Coleoptera			**Odonata**		
Wetland Comparisons	**Overall**	**ES**	**LS**	**Overall**	**ES**	**LS**
FOR - BC	**2.997***	**2.685***	2.227	-2.358	-1.886	-1.971
PA - BC	1.819	1.063	**2.654***	-1.643	-2.474	-0.162
SC - BC	**3.512****	2.502	**3.964*****	-0.507	-1.027	0.879
PA - FOR	-0.491	-0.899	0.988	-0.154	-1.591	1.07
SC - FOR	0.262	-0.508	1.892	1.91	0.675	**2.86***
SC - PA	0.661	0.583	0.095	1.438	2.087	0.862

Overall, 521 individuals of aquatic Coleoptera were collected over the two sampling periods (ES and LS) at the 40 study sites. There was one clear dominant family, Gyrinidae, making up 78.12% of the total. Four other families of aquatic Coleoptera were also sampled: Dytiscidae (14.59%), Haliplidae (5.37%), Hydrophilidae (0.96%) and Hydrochidae (0.96%). The dytiscids were the most species diverse family comprising six different genera and 14 taxonomically distinct species. Most individuals of aquatic Coleoptera sampled were from the genus *Orectogyrus* (Régimbart, 1884) (Coleoptera: Gyrinidae), which made up 62.38% of all aquatic Coleoptera individuals. The total number of aquatic Coleoptera species recorded was 22 (S_{obs}=22). The species accumulation curve (Fig. 2.1b) shows that possibly more sampling could have been done to achieve an accurate census of aquatic Coleoptera diversity. However, estimators used for the analysis suggest that most species were captured (S_{obs}=22, Chao2=24.57±2.82, Jacknife2=27.01; Fig. 2.1b).

Overall aquatic Coleoptera species richness was low at all four wetland groups with the highest collective richness being in FOR ponds (Fig. 2.2b). The results of various GLMM's show that there were no significant variables responsible for determining species richness in aquatic Coleoptera (Table 2.3). Tukey tests run on the aquatic Coleoptera data show that overall there was no significant difference in species richness between the four wetland types, over the two sampling periods (Table 2.5). This was also the case when the test was run on the two seasons independently. SC, FOR and PA sites all had similar species richness, whilst species richness at BC sites was lower (Fig. 2.2b)

Over the course of the two sampling periods a total of 3153 Odonata individuals were collected at the 40 sites. This number comprised 52.65% Zygoptera (damselflies) and 47.35% Anisoptera (dragonflies). Most Zygoptera were Coenagrionidae (37.20% of the total individuals), other recorded Zygoptera included Protoneuridae (5.65%), Synlestidae (4.15%), Platycnemididae (3.17%) and Lestidae (0.03%). Anisoptera was made up of three families: Libellulidae (35.97% of the total individuals), Aeshnidae (8.66%) and Gomphidae (2.73%). The most observed species in the study was *Pseudagrion kersteni* (Gerstäcker, 1869) (Odonata: Coenagrionidae) which accounted for 15.29% of the total recorded Odonata. The number of recorded *P. kersteni* individuals was more than twice the next most recorded species. In total, 33 species of Odonata were recorded over the two sampling seasons (S_{obs}=33). The species accumulation curve (Fig. 2.1c) begins to flatten off after about the 30th species showing that adequate sampling of Odonata was done, as also shown by two species estimators (S_{obs}=33, Chao2=33.5±1.03, Jacknife2=33.074; Fig. 2.1c). Although the total recorded Zygoptera comprised a higher percentage of the total observed Odonata individuals, the sub-order only had 13 recorded species compared to 20 Anisoptera species.

The GLMM's carried out to determine which variables were responsible for affecting overall species richness of Odonata found that none were significant. Looking at the two sampling seasons, ES Odonata species richness was not affected by any variable. However, in LS sampling, pH had a significant effect on Odonata species richness (Table 2.3). Tukey test showed that there was no significant differences in overall Odonata species richness between any of the four groups, however, from the results it is clear that large sugarcane sites had the highest species richness of Odonata when compared with the other four wetland groups (Fig. 2.2c; Table 2.5). This result was the same for both ES and LS sampling, with no significant differences between the four wetland groups being recorded.

Abundance

Aquatic Coleoptera abundance differed significantly between ES and LS, particularly in small sugarcane and forestry sites (Fig. 2.3a). Overall GLMM's indicated that abundance was significantly affected by wetland type and pH (Fig. 2.4; Table 2.4). Inter-seasonally, GLMM results were varied for aquatic Coleoptera abundance as in LS, wetland type, overall MAC cover, % sedge cover and % bulrush cover were significant determinants, whilst in ES, % LG cover was a significant determinant (Table 2.4). Tukey tests showed that there were significant differences between FOR and BC, as well as SC and BC (Table 2.6). When seasonality was taken into account, Tukey tests revealed significant differences between PA and BC, as well as SC and BC for LS aquatic Coleoptera abundance, whilst in ES only FOR and BC aquatic Coleoptera abundance was significantly different (Table 2.6).

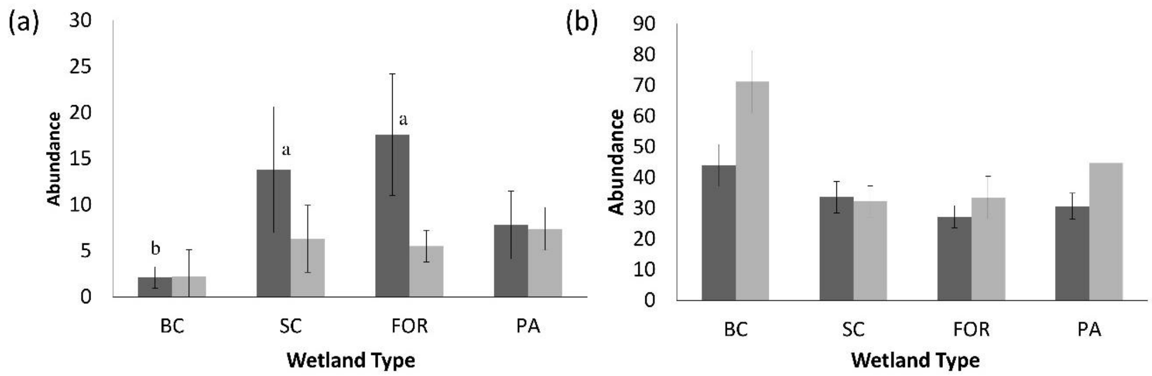


Figure 2.3. Abundances of focal taxa at the various wetland types. Aquatic Coleoptera abundance (a) and Odonata abundance (b) are shown here (Mean ± 1 Standard error). The dark bars indicate early season (ES) sampling whilst the grey bars indicate late season (LS) sampling. Different letters above bars show significant pairwise differences ($p<0.05$), therefore those without letters show no significant differences (BC = Big Cane, SC = Small Cane, FOR = Forestry and PA = Protected Areas).

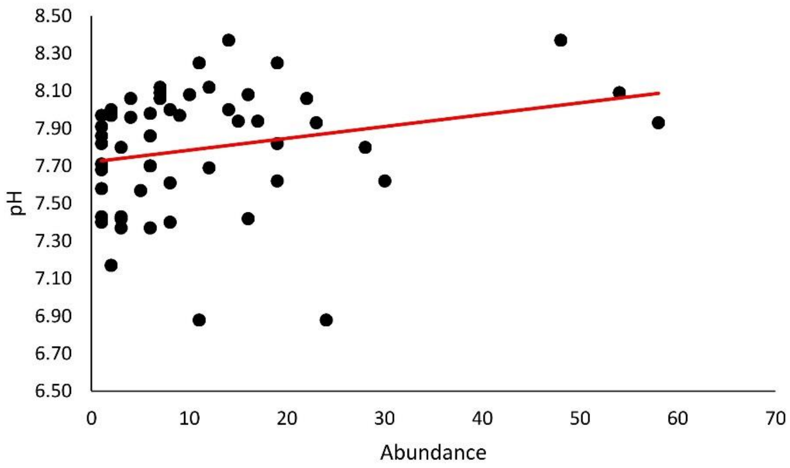


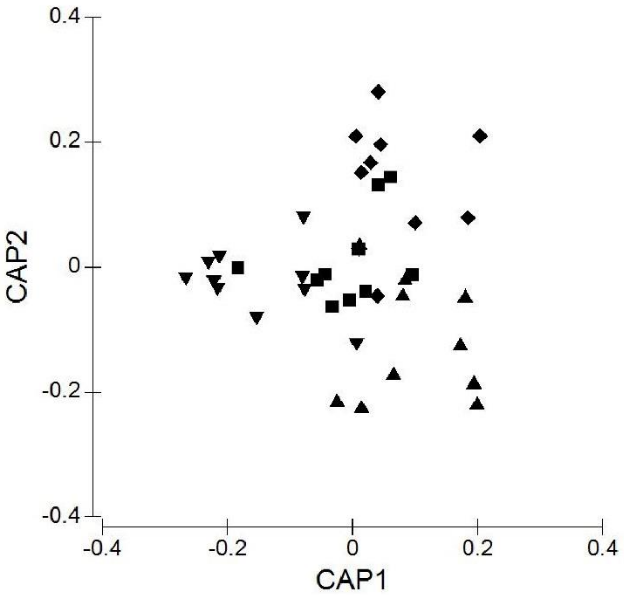
Figure 2.4. The relationship between pH and aquatic Coleoptera abundance. This was the only significant environmental variable for this taxon regarding species richness and abundance.

The results regarding Odonata species abundance encompass many environmental variables, which were implemented in this study for the purpose of better understanding the population dynamics of the order. The initial GLMM's indicated that cloud cover and wind speed significantly affected overall Odonata abundance (Table 2.4). Results for this group differed depending on season. The GLMM completed on ES Odonata data shows that proximity to crops significantly impacts Odonata abundance whereas in LS wetland type, pH, air temperature and humidity were the significant variables affecting Odonata abundance (Table 2.4). Tukey tests yielded no significant differences in overall Odonata species abundance between the wetland groups (Table 2.6). Tukey tests were then completed on the seasonal data where ES data also showed no significant differences between all four wetland groups (Table 2.6). However, in LS, a significant difference in Odonata species abundance was found between the SC and FOR wetland groups (Table 2.6).

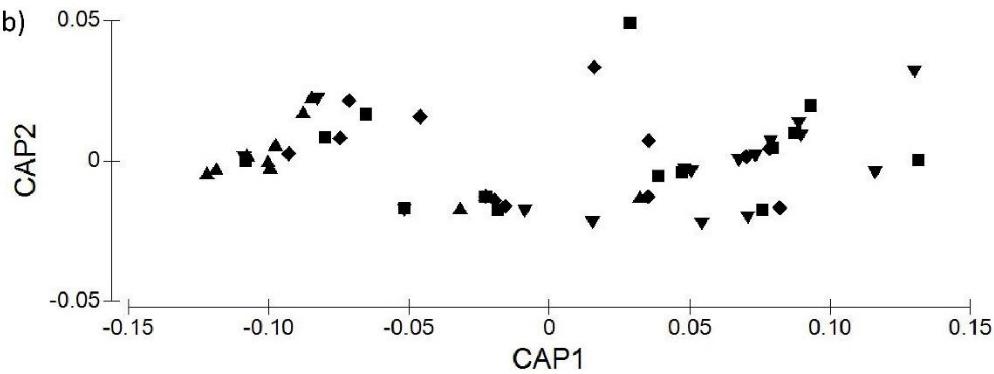
Species composition

The PERMANOVA indicated that overall there was a significant difference between all four site types (BC, SC, FOR and PA) (Table 2.7), with most pairwise comparisons showing significant differences in plant species composition (Table 2.8). Only SC and PA sites exhibited similar plant species composition (Fig. 2.6a; Table 2.8). Proximity of the wetland sites to agriculture was the only environmental variable to affect the species assemblage composition of plants (Table 2.7).

(a)


0.4
0.2
0
-0.2
-0.4
CAP2
-0.4
-0.2
0
0.2
0.4
CAP1

(b)


0.05
0
-0.05
CAP2
-0.15
-0.10
-0.05
0
0.05
0.10
0.15
CAP1

(c)

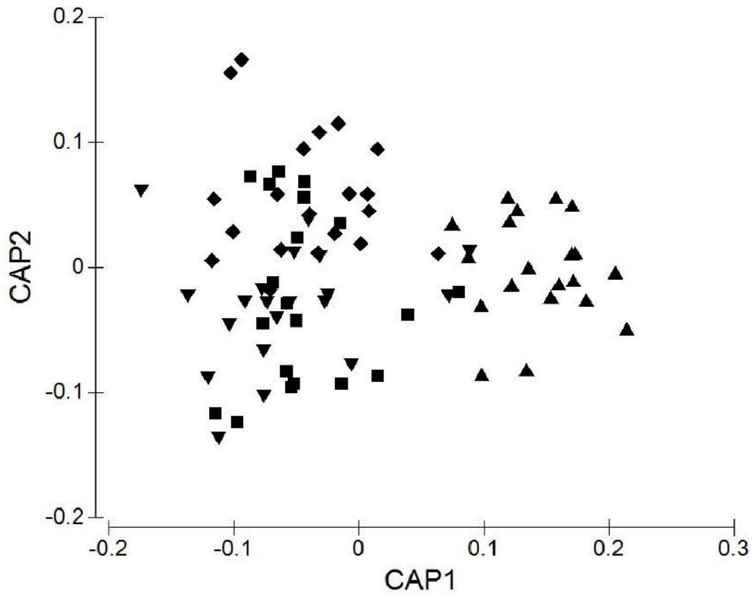


Figure 2.5. A canonical analysis of principal coordinates (CAP) of all three assemblages based on different wetland types. These graphs show the similarity of sites based of the composition of the three taxa. The three assemblages featured here are plants (a), aquatic Coleoptera (b) and Odonata (c). Triangle = BC, Inverted triangle = FOR, Square = SC and Diamond = PA.

Table 2.7. Results of overall (season and wetland type) and categorized (pH, dissolved oxygen, wetland diameter, proximity to crops, overall macrophyte cover, %Sedge, %bulrush and %long grass) PERMANOVA's. Bold values indicate a significant p-value, * < 0.05, ** < 0.01, *** < 0.001.

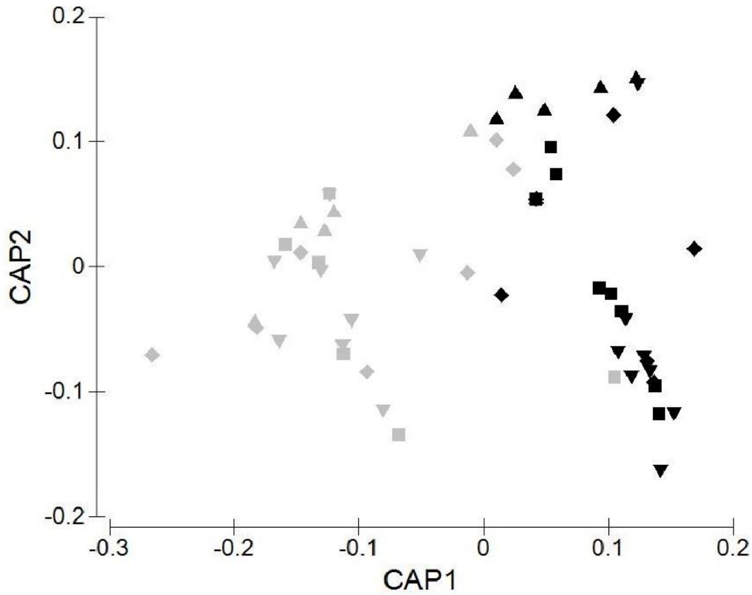
Variables	Plants Pseudo-F	Aquatic Coleoptera Pseudo-F	Odonata Pseudo-F
Overall Data			
Season		**11.445*** **	**5.177*** **
Wetland Type	**2.667*** **	1.756	**4.871** **
Categorized data			
pH	1.503	1.564	1.400
DO2	1.525	**2.064* **	**2.30** **
DIAM	1.371	**3.258*** **	**5.171*** **
PROX	**2.471*** **	0.795	**1.92* **
MAC		**2.991** **	**4.053*** **
%Sedge		**2.446** **	**4.452*** **
%bulrush		1.531	**4.199*** **
%LG		1.010	**2.893*** **

Table 2.8. Results of pairwise tests completed on wetland comparison data of plants, aquatic Coleoptera and Odonata. Bold values indicate a significant p-value, * < 0.05, ** < 0.01, *** < 0.001.

Wetland Comparisons	Plants Overall t value	Aquatic Coleoptera Overall t value	ES t value	LS t value	Odonata Overall t value	ES t value	LS t value
FOR - BC	**1.975*** **	**2.536*** **	**2.524** **	1.605	**3.280*** **	**2.767*** **	**2.2509*** **
PA - BC	**1.774** **	**1.495* **	**1.507* **	1.164	**2.680*** **	**2.305*** **	**1.9115*** **
SC - BC	**1.652** **	**1.742** **	**1.551* **	1.105	**3.066*** **	**2.273*** **	**2.3269*** **
PA - FOR	**1.746*** **	1.223	1.063	1.358	**1.586* **	1.395	1.1889
SC - FOR	**1.639** **	0.823	1.013	0.662	1.110	0.941	0.95578
SC - PA	1.053	0.760	0.735	1.010	**1.427* **	0.917	**1.4688* **

PERMANOVA of overall aquatic Coleoptera species composition of the four wetland groups indicated that there was similarity between FOR and SC, FOR and PA as well as SC and PA (Fig. 2.5b; Table. 2.8), with the overall species composition in BC sites being significantly different from the other three wetland groups (Fig. 2.5b; Table. 2.8).

(a)


CAP2
CAP1
0.2
0.1
0
-0.1
-0.2
-0.3
-0.2
-0.1
0
0.1
0.2

(b)

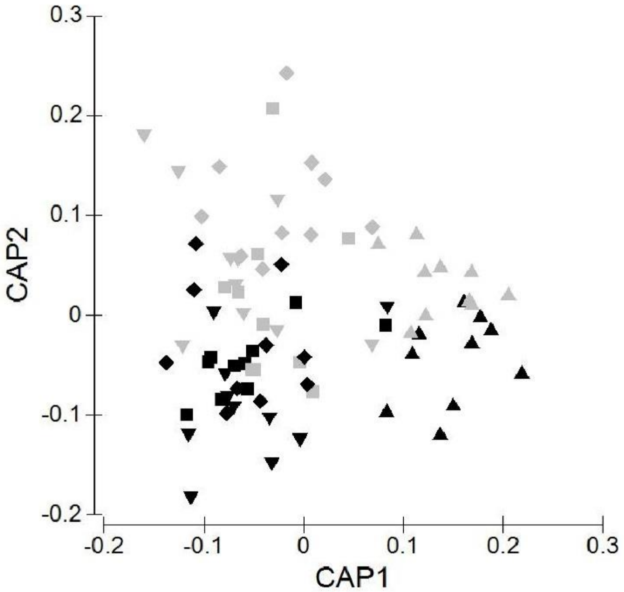

CAP2
CAP1
0.3
0.2
0.1
0
-0.1
-0.2
-0.2
-0.1
0
0.1
0.2
0.3

Figure 2.6. A canonical analysis of principal coordinates (CAP) analysis combining season and type for aquatic Coleoptera (a) and Odonata (b).Triangle = BC, Inverted triangle = FOR, Square = SC and Diamond = PA. Dark symbols indicate ES whilst grey symbols indicate LS.

A closer look at the seasonal species composition of aquatic Coleoptera (Fig. 2.6a; Table 2.7) revealed that sampling season had a significant effect on species composition, as BC was significantly different to all other wetland groups during ES, according to the PERMANOVA. Yet there were no significant differences in aquatic Coleoptera species composition during LS. There were four other environmental variables which had a significant effect on overall aquatic Coleoptera species composition: dissolved oxygen, pond diameter, overall MAC cover and % sedge cover (Table 2.7).

Overall compositional data on Odonata (Fig. 2.5b; Table 2.8) reveals that nearly all wetland groups showed significant differences between each other. Only FOR and SC had similar overall Odonata species composition (Fig. 2.5b; Table 2.8). PERMANOVA's were then completed with the focus on Odonata species composition in ES and LS. During ES, only species in BC sites were significantly different in composition when compared to the other three wetland groups (Fig. 2.6b; Table 2.8). In LS, this was also so, however, SC and PA also had significantly different Odonata species composition (Fig 2.6b; Table 2.8). From both the seasonal (Fig. 2.6b) and overall (Fig. 2.5c) CAP analyses, BC composition is highly significantly different to the other wetland groups (Table 2.8).

Further PERMANOVA's were constructed based on categorical environmental variables to determine whether any had an effect on Odonata species composition. A total of seven environmental factors had a significant effect: dissolved oxygen, pond diameter, proximity to crops, overall MAC cover, % sedge cover, % bulrush cover and % LG cover (Table 2.7).

Discussion

Plants

None of the wetland types were significantly different from each other in terms of species richness of plants at the sites. The forestry wetlands were the habitat type with the highest mean species richness overall. Bremer and Farley (2010) found that exotic plantations had lower plant diversity than native plantations. In this study all forestry sites were alien species, either *Eucalyptus* or *Acacia*, and yet still had higher plant species richness when compared with sugarcane and even protected area sites. Species composition, however, showed most catchments having significant differences from one another, except for the small sugarcane and protected area sites which had similar plant composition. The protected area sites were the least invaded, which was expected as they were chosen to provide a representation resembling the indigenous plant life which would have existed in the area prior to large scale agriculture being introduced. Moderate levels of disturbance are often seen as beneficial for biodiversity. However, high levels of disturbance create environments that can only be exploited by a few plant species (Battles *et al*. 2001).

The proximity of wetlands to agricultural practices was a significant factor determining the species composition of plant assemblages. Both the sugar cane sites (large and small) exhibited the highest levels of plant invasion, indicating that the sugarcane wetlands are highly modified, and as a result of disturbance, opportunistic invasive species are exploiting the habitat (Brockerhoff *et al*. 2003). Generally speaking, farmers in the area do not fully utilise the services provided by the natural watercourses on their land, in that their focus is solely on the management of rainfall. Farmers often use *Pennisetum clandestinum* (kikuyu grass) (Poales: Poaceae) in waterways to allow for maximum surface water absorption as large thunderstorms are common in the area and flash floods can cause excess water to sit in fields or wash away crops if waterways are not managed correctly. However, if they cleared the invasive grass and planted indigenous sedge species, such as *C. dives* and other sedges, this could reduce alien plant impacts on the land as well as make use of a pest regulatory function that wetlands provide (Rutherford 2015). However, the removal of invasive plants is a costly process. Yet the benefits of improved water availability and quality, as well as biodiversity conservation, illustrate the economic and overall importance of clearing (e.g. Turpie *et al*. 2008).

Aquatic Coleoptera

Sampling was representative of the aquatic Coleoptera population dynamics within the study area. The relatively low number of species, compared to other areas in KZN (e.g. Wishart and Day 2002), was reflected across all four of the different site groups with no statistical evidence suggesting any wetland type having housed a higher diversity of aquatic Coleoptera when compared with another. A high number of other aquatic insect species were observed in the reservoirs and ponds, mainly Odonata and Hemiptera. Although these bugs were not presented in the results, it is important to note that they were found in much higher numbers when compared to the aquatic Coleoptera. There is low incidence of aquatic Coleoptera species richness in KZN Midlands' reservoirs. In Samways *et al*. (1996), only two aquatic Coleoptera species were found out of a total 22 benthic invertebrate species present in a reservoir near

Dargle, in the KZN midlands. In the CFR, Apinda-Legnouo *et al*. (2013) found 40 aquatic Coleoptera species out of 57 total aquatic Coleoptera and bugs in mostly permanent pond sites. From the sampling of 80 sites and accounting for seasonal change, only 22 different aquatic Coleoptera species were identified here, suggesting that species richness of this group is relatively low in the south Midlands of KZN. Interestingly there were no significant differences in species richness between the four wetland types which includes data from protected area sites. This illustrates that, in this area of KZN at least, agriculture seems to have a negligible effect on aquatic Coleoptera species richness within these ponds. Certain landowners are putting effort into the conservation of their natural watercourses, however, a greater overall effort is required if aquatic Coleoptera species richness is to increase. It is possible, however, that the general degree of agriculture and high land-use by farmers in the south Midlands area may negatively affect overall species richness of this particular insect group.

Both species richness and abundance of aquatic Coleoptera appears to be highly localised, which would account for the low average numbers obtained. For example, in the late summer sampling in large sugarcane ponds, five out of the 10 reservoir sites yielded zero aquatic Coleoptera individuals. This points towards the current low effort that certain individual land owners are putting in to conserve their ponds and reservoirs. The pH of water bodies was the only environmental variable to have a significant effect on aquatic Coleoptera abundance. Past studies (Waterkyn *et al*. 2008; Apinda-Legnouo *et al*. 2013) have found that pH is important for determining the community structure and species composition of aquatic Coleoptera but not necessarily abundance. Generally, increasingly acidic conditions of water bodies correlates with lower species richness of invertebrates (e.g. Hinden *et al*. 2005; Bradford *et al*. 1998). Bradford *et al*. (1998) alternatively found that pH bears little or no relationship with macroinvertebrate distribution or abundances, while, in this study I found a positive relationship between pH and aquatic Coleoptera abundance. Lower pH would have a negative effect on the exoskeleton development of aquatic beetles, as in other invertebrates, which could account for lower populations in water bodies that are more acidic (Arnold *et al*. 2009).

Seasonality had a substantial effect on aquatic Coleoptera abundance, particularly within the small sugarcane and forestry pond sites. This was mostly due to localised high abundance of certain species such as the whirligig beetle *Orectogyrus*, which is known to aggregate in large numbers for predator avoidance (Vulinec and Miller 1989). Other species of aquatic Coleoptera were sparingly distributed over the study area with some species exhibiting very low abundance, such as the *Africophilus* genus from which only one individual was collected.

This is in line with Samways *et al*. (1996) where only two species of aquatic Coleoptera were found with one species accounting for 30 out of 33 total individuals.

Compositional data of aquatic Coleoptera species showed that ponds and reservoirs in the large sugar cane areas comprised different species when compared with the other three wetland groups over both sampling periods. These differences only occurred in early summer, with late summer providing no significant differences in aquatic Coleoptera species composition in the four wetland groups. This indicates that seasonality was the dominant factor in determining the composition of aquatic Coleoptera species in this study. Mating season for most insects occurs from spring through to summer which can explain why abundance was higher in early summer, during the height of mating season, rather than late summer when mating season would be decreasing.

Other factors including dissolved oxygen, reservoir/pond diameter, overall macrophyte cover and percentage sedge cover all had significant effects on aquatic Coleoptera species composition (Table 2.7), which contrasts with the CFR results of Apinda-Legnouo *et al*. (2013) where aquatic Coleoptera composition was not affected by dissolved oxygen, riparian vegetation cover or pond size. Furthermore, Hinden *et al*. (2005) found that increased conductivity resulting from anthropogenic activities such as agriculture and land clearing can decrease species richness in ponds. However, here I found that overall aquatic Coleoptera species richness was low due to overall low aquatic Coleoptera diversity in the area. Presence of fish may play a key role in accounting for the low density of aquatic Coleoptera within my study sites. A study by Weir (1972) found that in a pond hosting the fish *Clarias gariepinus* (African sharptooth catfish) (Siluriformes: Clariidae) seven aquatic Coleoptera species were present whilst in a similar pond without the fish, 31 aquatic Coleoptera species were recorded and at a substantially higher density. Fairchild *et al*. (2000) also indicated that the presence of fish had a major influence on overall aquatic Coleoptera species abundance. Many landowners in the south Midlands area stock their reservoirs and ponds with *Micropterus salmoides* (Largemouth bass) (Perciformes: Centrarchidae) for recreational purposes. The introduction of these non-native fish could be the significant factor for decreased populations of aquatic Coleoptera in the area.

Odonata

The highest species richness and abundance of Odonata was in ponds and reservoirs of large sugarcane sites. The average size of the water bodies in large sugarcane was much larger than in other catchment types, indicating that pond/reservoir diameter plays some role in determining species richness and abundance of Odonata. Kadoya *et al*. (2004) had similar conclusions in that increased pond area increased species richness of adult Odonata, and they suggested from random placement theory that immigration of individuals to a pond is linearly proportional to the area of the pond (Coleman *et al*. 1982). However, this approach has weaknesses and accordingly the relationships are not always perfect, although a clear pattern did exist in their study (Kadoya *et al*. 2004). Oertli *et al*. (2002) also found that a larger pond area supported more Odonata species but not necessarily for other taxa such as Coleoptera and Amphibia. This result is contrary to the study by Osborn and Samways (1996) where they found that species richness of Odonata was low at large ponds compared with a higher species richness at smaller ponds at the same location, and was attributed to the biotope complexity and heterogeneity of smaller ponds (Osborn and Samways, 1996). Although the species richness of Odonata was highest in my BC sites, they mostly comprised common generalist species such as *Anax imperator* (Odonata: Aeshnidae). Simaika and Samways (2009) found that an increase in species richness of Odonata corresponds with a decrease in endemism and, according to my results, this appears to be the case for the large sugarcane sites, which were primarily water reservoirs, which are known to increase the abundance of certain generalist Odonata species in the same general geographical area (Samways 1989). Interestingly, small sugarcane sites had the lowest Odonata diversity indicating that, for sugarcane areas at least, the size of the pond is relevant to species richness. The small and large sugarcane sites are located within areas of intensive sugarcane agriculture, with the vegetation in and around the ponds being highly disturbed, mainly from invasive plants. Accordingly, biotope complexity could not overcome the size limitations of small ponds as it did in Osborn and Samways (1996) where some sites were in lesser disturbed areas. It is also apparent that Odonata species composition in the large sugarcane sites is significantly different from all other wetland groups.

The species richness of Odonata within the forestry sites was the third lowest of the four wetland groups. *Eucalyptus* (Myrtales: Myrtaceae) trees reduce water flow, inhibit vegetation growth beneath the canopies as well as increase the acidity of the soil (e.g. Johns 1993). Furthermore, invasive black wattle (*Acacia mearnsii*) (Fabales: Fabaceae) trees are known to be one of the most important threats to endemic South African Odonata (Samways and Taylor 2004). The dense canopies of these trees, particularly *A. mearnsii*, shade out suitable habitat, reducing Odonata species richness and abundance (Kinvig and Samways 2000). My forestry sites were not completely shaded by the alien plantation vegetation, although the height of the trees within the plantations, particularly eucalypt species, meant that shading would occur over parts of some ponds in the morning and evening, which could play a role even if this is the time of day when Odonata are mostly inactive (Samways and Sharratt 2010).

Clark and Samways (1996) found a negative correlation between shade cover and Anisoptera (Sub-order of Odonata) species richness. Yet here I found that the effects of forest shading were negligible as Anisoptera and Zygoptera (both sub-orders of Odonata) were equally well represented in both the sugarcane sites and the forestry sites. Some protected area sites were also in shaded areas although all, or most, of the trees would have been indigenous. Species richness of Odonata was slightly lower in the protected area sites compared to the big cane sites. However, the protected area sites housed more endemic species (e.g. *Allocnemis leucosticta* (Odonata: Platycnemididae) or *Aeshna subpupillata* (Odonata: Aeshnidae)) which are known to be vulnerable to disturbance (Samways and Sharratt 2010).

Overall Odonata abundance had a significant relationship with wind speed and cloud cover. The chief reason for this is that sampling was, for the most part, completed on cloudless, windless days although the quality of weather would occasionally deteriorate later on in the day due to afternoon thunderstorms, which are common in the study area (Welsford and Johnson 2011). Sampling Odonata on days with low cloud cover and wind speed is crucial as this is when Odonata are most active therefore maximum data can be collected (e.g. Samways and Sharratt 2010).

I found that Odonata species composition was significantly affected by seven environmental variables: dissolved oxygen, pond diameter, proximity to crops, overall aquatic macrophyte cover, percentage sedge cover, bulrush cover and long grass cover. Riparian vegetation clearly plays a role in determining Odonata assemblages which has been found in previous work (e.g. Remsburg and Turner 2009). The structure of the riparian plants is important as the tall and rigid plants (e.g. *Phragmites australis* (Poales: Poaceae), *Typha capensis* (Poales: Typhaceae), etc.) provide suitable habitat for the nymphs of some Odonata species and also for adult Odonata to perch optimally, so promoting thermoregulation as well as mate attraction (Corbet 1999; Pezalla 1979; Mckinnon and May 1994). Pryke *et al*. (2015) showed that dissolved oxygen in water had a significant effect on species richness but not on species composition of adult Odonata. They did find, however, that species composition was affected by the distance to plantations as well as percentage reed and vegetation cover, which I also found here.

Conclusions and recommendations for conservation

Ponds and reservoirs within agricultural areas comprised similar and at times higher species richness than protected areas which highlights the value that these water bodies possess in terms of maintaining aspects of regional biodiversity (Briers and Biggs 2005; Pryke *et al*. 2015), even though these species may not be the rarest or the most in need of conservation management. Local farmers are clearly putting effort into the maintenance and conservation of their waterways. However sugarcane wetlands are severely invaded by alien plants such as *Rubus fruticosus* L. (Rosales: Rosaceae), but nevertheless they support many native Odonata species. The south Midlands area is mostly a sugarcane growing zone, and the reservoirs and ponds within the water courses of farms provide these insects with much needed habitat. The results of this study were slightly different than expected, with diversity in forestry sites not as high as in sugarcane sites. However, forestry sites did support important specialist and endemic Odonata species (e.g. *Chlorolestes tessellatus* (Odonata: Synlestidae) and *Allocnemis leucosticta* (Odonata: Platycnemididae)) which is significant from a conservation point of view. Farmers in sugarcane areas should be made more aware of the importance that reservoirs and ponds have for local species conservation, which includes mammals and birds as well as insects.

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Chapter 3

The conservation significance of ponds and reservoirs for Odonata in a sugarcane-forestry mosaic

Abstract

Farm ponds act as habitat islands and are known to support heterogeneous communities of aquatic organisms which often include rare or unique species not found in other water body types. In the southern KwaZulu-Natal (KZN) Midlands, ponds and reservoirs play a major role in increasing populations of some Odonata species and so contribute to the overall conservation of Odonata. In this study, I investigate the localised and threatened Odonata species, as well as utilise the Dragonfly Biotic Index (DBI) to assess the Odonata conservation significance of ponds and reservoirs in a sugarcane-forestry mosaic. To accomplish this, I sampled the adult Odonata species of ponds and reservoirs from three different catchment types: forestry, sugarcane and protected areas. These species were assigned DBI scores which were then used to indicate the ecological integrity of each system. My results show that sites at large sugarcane ponds had the lowest DBI scores whilst sites in protected areas exhibited the highest scores. This indicates that species that are sensitive to disturbance are unable to use the large sugarcane ponds. Despite this finding, sugarcane ponds were able to support many species of Odonata, mainly widespread generalists that were not sampled in the protected area. Ponds in forestry agriculture supported some specialist species, however, no Odonata individuals were found exclusively at these sites. Here, species richness of Odonata was a poor indication of pond conservation value and I recommend using DBI for future monitoring. Although the sugarcane farms were able to support high numbers of generalist species, these results indicate that farmers could be doing more to encourage environmentally sensitive species into their wetlands.

Keywords: Farm ponds; ecological integrity; Odonata; DBI; biodiversity

Introduction

Farm ponds and reservoirs are known to have significant conservation value due to their importance in biodiversity conservation (Samways 1989). However, only recently has their contribution towards the regional diversity (gamma diversity) become acknowledged (Biggs *et al*.1994; Oertli *et al*. 2002; Declerck *et al*. 2006). Farm ponds worldwide are known to support heterogeneous communities of aquatic organisms which often include rare or unique species not found in other water bodies, such as streams or rivers. (Oertli *et al*. 2002; Williams *et al*.

2004). In spite of the importance of farm ponds for provision of habitat for aquatic species, they are under threat from a range of sources including chemical pollution, eutrophication from agricultural runoff, land-use change, physical destruction and invasion by non-native species (Declerck *et al*. 2006; Curado *et al*. 2011; Takamura 2012).

South Africa is, for the most part, a semi-arid country and as a result farm pond and reservoir creation is essential for water conservation and sustainable use. In recent times, sugar and timber farmers in South Africa have begun implementing environmentally friendly farming techniques (FSC standards and SUSFARMS ®, respectively; Chapter 2) which prioritises areas of land on the farmers' properties for natural habitat conservation, which in turn encourages local biodiversity conservation (FSC 1996; Maher 2007). One of the key aspects of sustainable farming is efficient hydrological management (Maher 2007). The creation of reservoirs as well as good management of wet areas on farms (e.g. waterways and drains) could have a positive effect on biodiversity. Farm ponds created on historic water courses and wetlands were described as habitat islands for macroinvertebrates by Bilton *et al*. (2008), which is an accurate description owing to their importance to native species which once would have resided within these naturally formed wetlands in KZN. These water bodies, in KZN are mostly perennial, although some do dry out in severe drought, as was the case in 2015 (South African Weather Service 2015).

Brinck (1955) stated that reservoirs on farms clearly attract new populations of Odonata (Odonata is used to represent both of the dragonfly sub-orders: Anisoptera and Zygoptera, unless explicitly stated otherwise), which possibly would not have existed prior to reservoir construction. Samways (1989) showed that ponds and reservoirs play a major role in increasing certain populations of Odonata, as well as contributing to the overall conservation of Odonata, particularly at lower elevations of KZN. Samways (1989) also noted that farmers should be made aware that the ponds and reservoirs are important contributors to insect conservation.

Although species richness and abundance data are an adequate biodiversity measure for an area, there are some problems, such as the degree of sampling effort, which can undermine the results (Simaika and Samways, 2009a). Bioindicators are therefore highly valuable for monitoring an ecological community as it involves the use of an organism which is representative of the composition, structure and functioning of a system to indicate the change of a habitat over time (e.g. Pearson 1994). Odonata are strong bioindicators as they are: (1) taxonomically well known, (2) relatively easy to identify in the field, (3) reside in a variety of habitats, (4) sensitive to water quality and environmental alterations, and (5) have a suitably sized species assemblage for adequate habitat assessments (Samways and Steytler 1996; Chovanec and Waringer 2001; Simaika and Samways 2011). The Dragonfly Biotic Index (DBI) is a biodiversity measure which uses presence/absence data of local Odonata to measure habitat recovery (Samways and Taylor 2004), freshwater health (Oertli 2008), ecological integrity (e.g. Chovanec and Waringer 2001) as well as climate change (Ott 2008).

In this study I investigate the use of the DBI in assessing the ecological integrity of ponds and reservoirs in a sugarcane-forestry mosaic within KZN. The goal is to show whether the high species richness values of farm ponds (Chapter 2), is due to wide ranging generalist species, or includes species with higher conservation value, in particular for range restricted and specialist species. This will help to quantify the true conservation value of these farmland ponds and reservoirs, which will hopefully then encourage farmers and land-owners to be more aware and considerate when it comes to management of these aquatic systems.

Materials and methods

Sampling layout

Sampling was conducted on commercial sugarcane and timber estates, approximately 40 km south-east of Pietermaritzburg, KZN, South Africa, 45 km from the coast at an elevation range of 500-900 m a.s.l. A total of 40 wetlands were selected as sites at which Odonata were sampled. The 40 total of sites comprised ten sites in historic natural habitat, 20 sites within sugarcane catchments (ten in large ponds and ten in small ponds) and ten sites within forestry catchments (Chapter 2; Sampling layout). The sites within the protected areas (PAs) were used for a baseline DBI, to which sites within the transformed areas can be compared. The sites in the forestry catchment (FOR) were variable in size, whilst ten sites within the sugarcane catchment were fairly large and were described in analyses as BC ('big cane'), subsequently there were ten SC ('small cane') sites which were relatively small allowing for a range of data to be collected on water bodies in sugarcane catchments, which are understudied in South Africa (Chapter 2; Table 2.1).

Odonata sampling

Odonata sampling took place from February to April 2014 and then again from November until December of 2014. Adult Odonata individuals were counted by walking through and around the specific study sites for about 100 m, stopping at appropriate times to confirm identity using close-focus binoculars (Samways and Sharrat 2009). Observations of Odonata took place over four 20 min sessions (twice per season), where all species in the area could be accounted for (i.e. the species accumulation curves flattened out). Species that were not easily identified were caught with a standard insect net and inspected more closely. In some cases species were preserved through freezing and brought back to the laboratory in a small ice chest where the identifications could be confirmed through expert opinion. During Odonata sampling, the environmental variables temperature, humidity, wind speed and cloud cover (CC) were also recorded. *Trithemis furva* and *T. dorsalis*, two Odonata species that are virtually indistinguishable in the field, were grouped together as a species complex during initial fieldwork. However, upon further examination it became clear that the morphospecies was most likely *T. furva* due to distribution patterns as well as elevation (Samways 2008). Odonata observations took place on warm days with minimal cloud cover, between 11h00 and 15h00, which was deemed to be an appropriate set of conditions as this is when adult Odonata are most active, therefore giving a comprehensive sample of Odonata species present at a given site (Samways and Sharratt 2010).

Environmental variables

Environmental variables collected from the waterbodies at the sites were pH, using a testo 206-pH1 hand held meter and dissolved oxygen, using a Hanna HI 9142 meter. Air temperature, humidity and wind speed were recorded using a Kestrel 4000 Pocket Weather Tracker (see Table 2.2 for details). Other site variables recorded included elevation, proximity to agriculture (PROX) and water body diameter (DIAM) which was calculated using Google Earth. Finally, the following were visually estimated using site photographs: % macrophyte cover (MAC), % sedge cover, % bulrush cover and % long grass (LG) cover.

Dragonfly Biotic Index

The Dragonfly Biotic Index (DBI), which measures the overall habitat integrity of an ecosystem, was used in this study to evaluate the ecological health of the wetland sites. (Simaika and Samways 2008; Simaika and Samways 2009a). The DBI system primarily relies on whether Odonata are present or absent at a particular locality and comprises three sub-indices that give a total DBI score for individual Odonata species. These sub-indices are: (1) geographic distribution, (2) threat status according to the IUCN Red List (IUCN 2008) and (3) species sensitivity to habitat conditions (Simaika and Samways 2009a, 2011). The three sub-indices are scored from 0 to 3, giving a total score of between 0 and 9 for each species. A score of 0 would be representative of a species which is widespread, of Least Concern according to IUCN assessments and not affected by habitat alteration, whilst a score of 9 would indicate a species which is rare, Endangered (EN) or Critically Endangered (CR) according to IUCN, and highly susceptible to habitat modification (Table 3.1). The DBI score of South African species is given in Samways (2008). In this study, total DBI per site, as well as average DBI per site, were calculated. To arrive at the total DBI per site, the DBI score of each site was totalled. The use of average DBI per site is more accurate in determining habitat integrity as it takes into account species richness (i.e. total DBI is divided by the number of species at each site). Average DBI score per site is the preferred way of measuring the ecological integrity of a site as it takes into account the score of all species, some of which may bring the score down greatly (i.e. species with values of 0) (e.g. Simaika and Samways 2009a, 2011).

Table 3.1. The sub-indices of the Dragonfly Biotic Index as adapted from Simaika and Samways (2009a). Threat status measurements provided are courtesy of the IUCN (2008): *GS* is an acronym for Global Status whilst *NS* is an acronym for National Status.

	Sub-indices		
Score	Distribution	Threat	Sensitivity
0	Common throughout South Africa and southern Africa	Least Concern; GS	Not Sensitive; marginally affected by habitat disturbance; possibly benefits from alien plant introduction; can thrive in artificial waterbodies
1	Localised across a large area in South Africa, and localised or common in southern Africa; or common in between 1 and 3 provinces and common in southern Africa	Near Threatened; GS or Vulnerable; NS	Low sensitivity to habitat alteration by alien plants; may be common in artificial waterbodies
2	National endemic species that is found in 3 or more provinces; or common throughout southern Africa but rare in South Africa	Vulnerable; GS or Endangered; NS or Critically Endangered; NS	Medium sensitivity to habitat alteration by alien plants and bank disturbance; possibly be recorded in waterbodies
3	Endemic or near-endemic, confined to 1 or 2 provinces	Critically Endangered; GS or Endangered; GS	Extremely sensitive to habitat alteration by alien plants; only found in pristine natural habitats

Statistical analyses

A linear mixed-effects model was used as the data were normally distributed according to a Shapiro-Wilks- W test after the data were log transformed. The model was created with the DBI scores as the response variable in R using the *lme4* package (Bates and Sarkar 2007; R Development Core Team 2013). This model was built with wetland type, pH, DO_2, DIAM, PROX, MAC, % sedge cover, % bulrush cover, % LG cover, as fixed variables and elevation as a random variable. Post-hoc analysis was performed on the water body type using a Tukey post-hoc test in the R package *multcomp* (Hothorn *et al*., 2008).

Results

Log DBI data was normally distributed according to the Shapiro-Wilks w test (W = 0.987, p= 0.599). These models show that habitat type, DO_2 and % LG cover all have a significant impact on the log DBI values (Fig. 3.1; Table 3.2). A subsequent Tukey post-hoc test showed that log DBI per site scores were significantly different between FOR and BC sites, as well as PA and BC sites (Fig. 3.2: Table 3.3).

Table 3.2. Results of Dragonfly Biotic Index scores analyzed using linear mixed models to show the response of Odonata to various environmental variables. Bold chi-square values indicate significance, * < 0.05 (significant), ** < 0.01 (very significant), *** < 0.001 (highly significant).

Variables	χ^2
Type	**12.345****
pH	0.0879
DO2	**1.1016**
DIAM	0.0007
PROX	3.5296
MAC	0.0422
%Sedge	0.133
%Bulrush	0.1447
%LG	**5.2492***

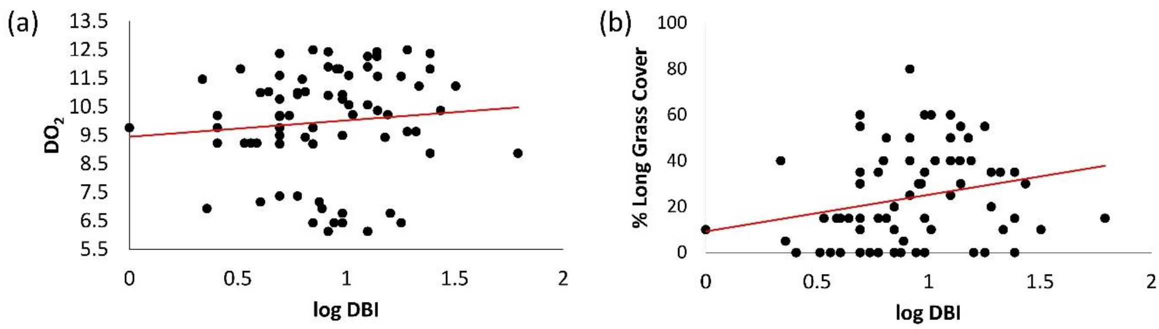


Figure 3.1. Significant relationships between DBI and DO_2 (left) and % LG cover (right).

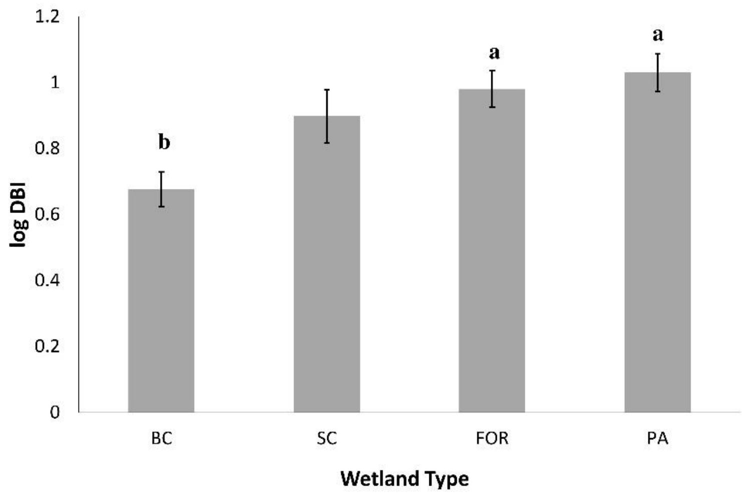
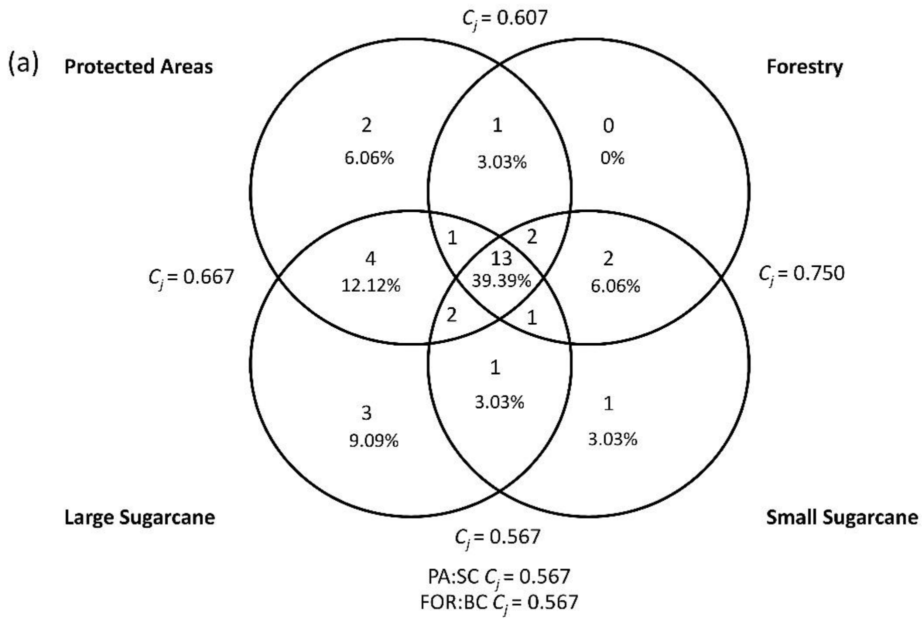


Figure 3.2. Log Dragonfly Biotic Index of Odonata at the various wetland types over the entire sampling period. BC = Big Cane, SC = Small Cane, FOR = Forestry and PA = Protected Areas. Mean ± 1 Standard error. Different letters above bars show pairwise differences, while those without letters show no significant differences.

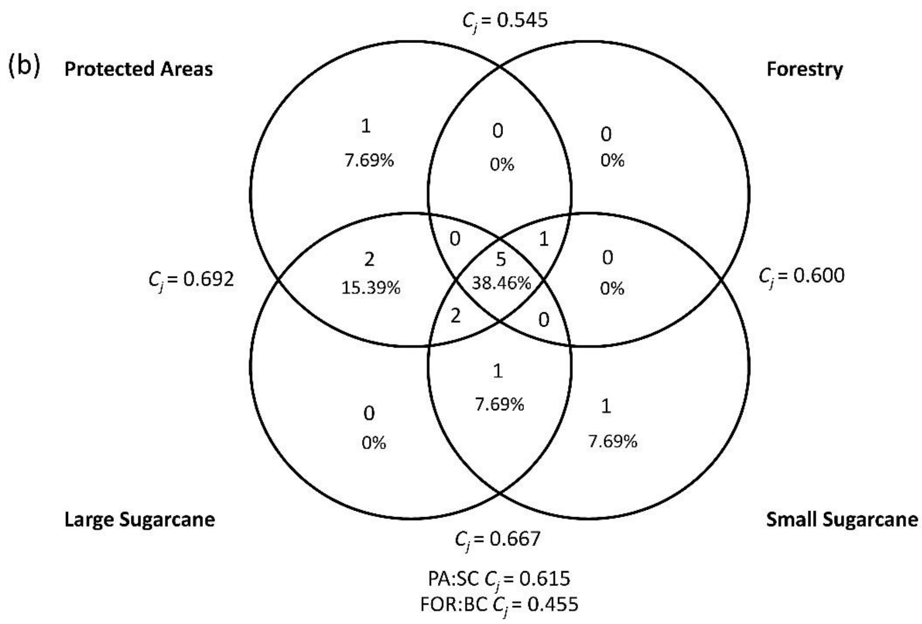
Table 3.3 Tukey pairwise test tables from GLMM data comparing different wetlands with regards to Log Dragonfly Biotic Index scores. Bold z- values indicate a significant p-value, * < 0.05, ** < 0.01, *** < 0.001.

Wetland Comparisons	Log DBI Data Overall z value
FOR - BC	**2.889***
PA - BC	**3.368****
SC - BC	2.113
PA - FOR	0.479
SC - FOR	-0.776
SC - PA	-1.256

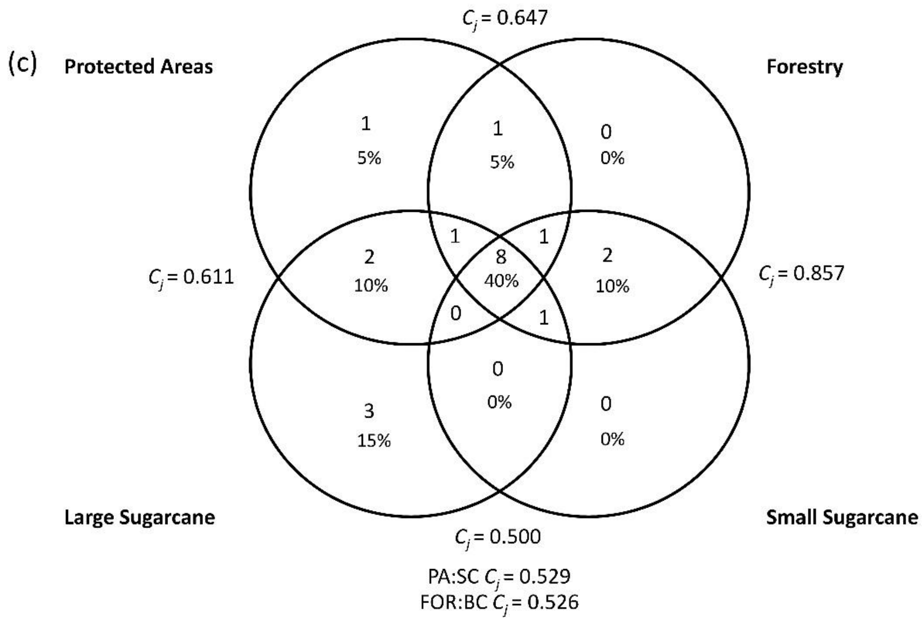
Twenty two of the 33 total Odonata species were found in both the sugarcane and PA sites (Fig. 3.3(a)). In the case of the Zygoptera 10 of 13 total species were shared between these two pond types (Fig. 3.3(b)). The Anisoptera, species were most similar in the forestry and small sugarcane sites (Fig. 3.3(c)). PAs showed higher similarity of Anisoptera with forestry than with sugarcane (Fig. 3.3(c)). Widespread species were greatly shared between the PAs and sugarcane sites (Fig. 3.3(d)). The coastal Odonata were primarily in the sugarcane catchment, as all coastal species from the study were recorded there (Fig. 3.3(e)). Interestingly, there was high similarity in the montane species among the agricultural sites (Fig. 3.3(f)). Small sugarcane sites showed high similarity of Odonata species with forestry sites while large sugarcane sites shared many species with PA sites (Fig. 3.3 (g)). The PA sites supported two species that were not sampled at any other wetland type: *Pseudagrion citricola* (Odonata: Chlorocyphidae), which is a South African endemic, and *Aeshna subpupillata* (Odonata: Aeshnidae) (Fig. 3.3(a)). Five Odonata species were sampled only at the sugarcane sites with *Tramea limbata* (Odonata: Libellulidae), *Urothemis assignata* (Odonata: Libellulidae) and *Rhyothemis semihyalina* (Odonata: Libellulidae) only being found at BC sites, *Lestes plagiatus* (Odonata: Lestidae) at SC sites and *Ischnura senegalensis* (Odonata: Chlorocyphidae) at both BC and SC sites (Fig. 3.3(g)). No species was unique to the forestry sites.

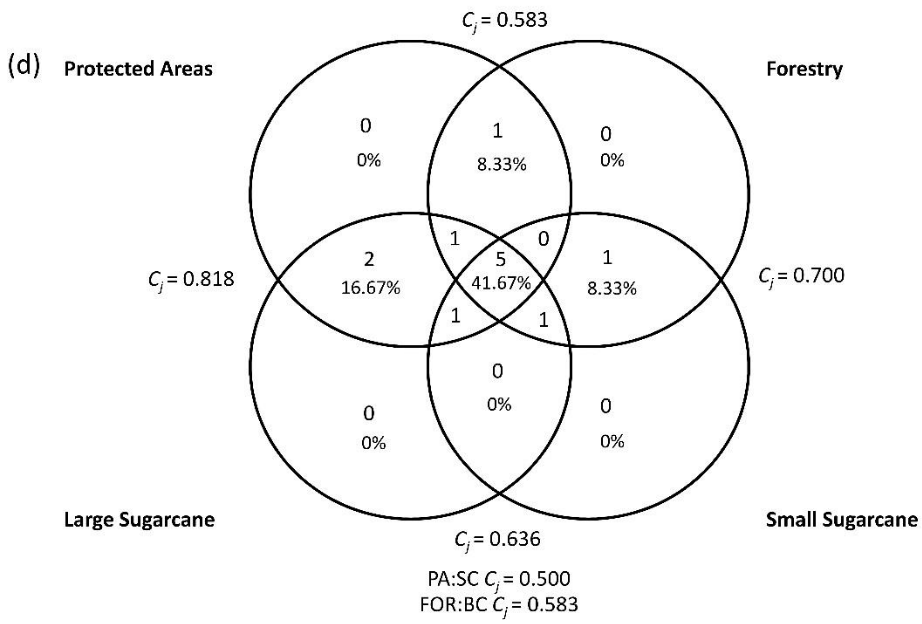


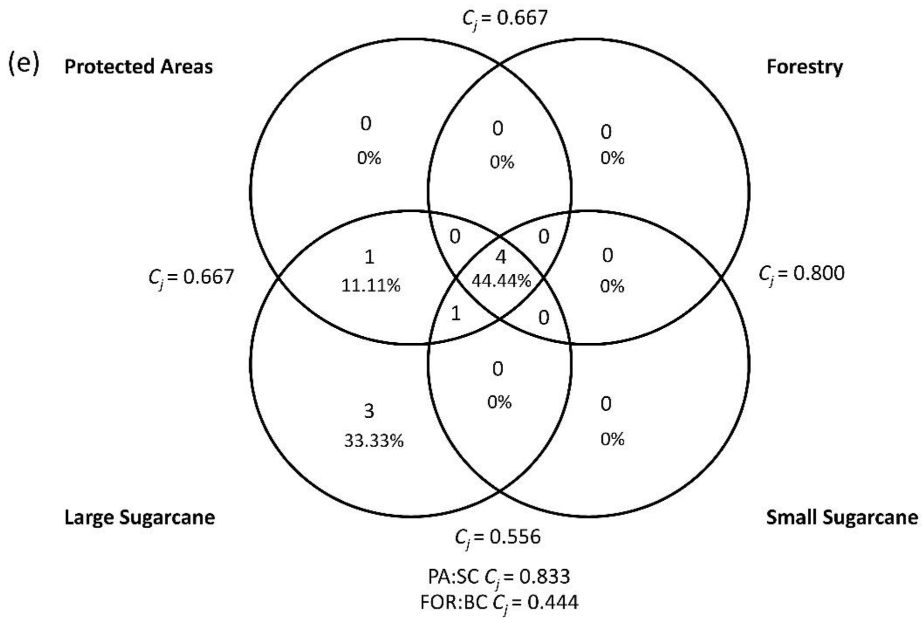
C_j = 0.607
(a)
Protected Areas
Forestry
2
6.06%
1
3.03%
0
0%
1
2
4
12.12%
13
39.39%
2
6.06%
C_j = 0.667
C_j = 0.750
2
1
1
3.03%
3
9.09%
1
3.03%
Large Sugarcane
Small Sugarcane
C_j = 0.567
PA:SC C_j = 0.567
FOR:BC C_j = 0.567



C_j = 0.545
(b)
Protected Areas
Forestry
1
7.69%
0
0%
0
0%
0
1
2
15.39%
5
38.46%
0
0%
C_j = 0.692
C_j = 0.600
2
0
1
7.69%
0
0%
1
7.69%
Large Sugarcane
Small Sugarcane
C_j = 0.667
PA:SC C_j = 0.615
FOR:BC C_j = 0.455


(c)
C_j = 0.647
Protected Areas
Forestry
1
5%
1
5%
0
0%
1
1
2
10%
8
40%
2
10%
C_j = 0.611
C_j = 0.857
0
1
0
0%
3
15%
0
0%
Large Sugarcane
Small Sugarcane
C_j = 0.500
PA:SC C_j = 0.529
FOR:BC C_j = 0.526


(d)
C_j = 0.583
Protected Areas
Forestry
0
0%
1
8.33%
0
0%
1
0
2
16.67%
5
41.67%
1
8.33%
C_j = 0.818
C_j = 0.700
1
1
0
0%
0
0%
0
0%
Large Sugarcane
Small Sugarcane
C_j = 0.636
PA:SC C_j = 0.500
FOR:BC C_j = 0.583


(e)
Protected Areas
Forestry
Large Sugarcane
Small Sugarcane
C_j = 0.667
C_j = 0.667
C_j = 0.800
C_j = 0.556
0
0%
0
0%
0
0%
0
0
1
11.11%
4
44.44%
0
0%
1
0
0
0%
3
33.33%
0
0%
PA:SC C_j = 0.833
FOR:BC C_j = 0.444

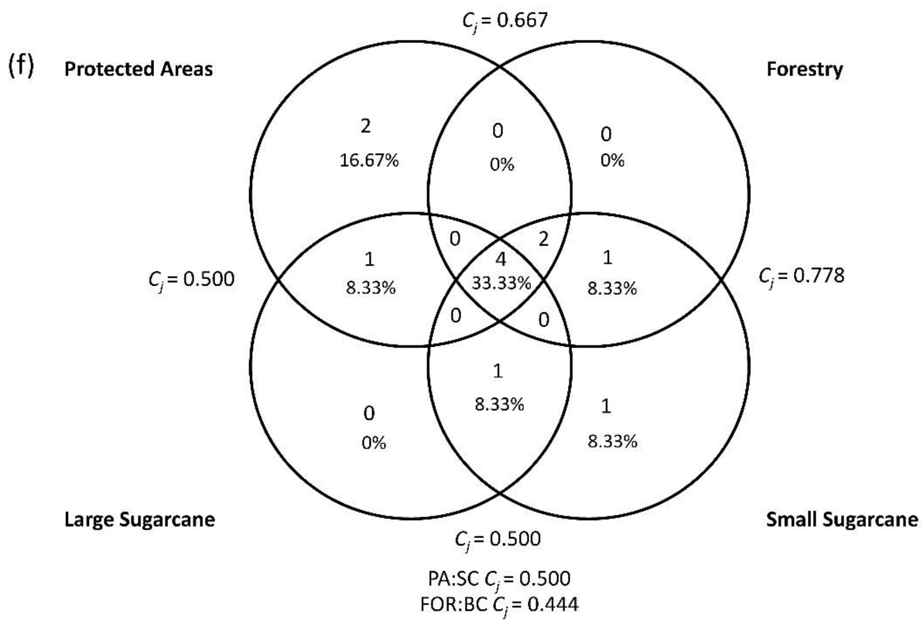

(f)
Protected Areas
Forestry
Large Sugarcane
Small Sugarcane
C_j = 0.667
C_j = 0.500
C_j = 0.778
C_j = 0.500
2
16.67%
0
0%
0
0%
0
2
1
8.33%
4
33.33%
1
8.33%
0
0
1
8.33%
0
0%
1
8.33%
PA:SC C_j = 0.500
FOR:BC C_j = 0.444

Figure 3.3. Venn diagrams showing the shared Odonata species within the three dominant site types of this study (protected areas, forestry and sugarcane). The Odonata species are arranged as six groups: (a) All Species, (b) Zygoptera, (c) Anisoptera, (d) Widespread (Coastal and Montane Species), (e) Coastal Species and (f) Montane Species. Jaccard Index (C_j) of similarity is shown between the wetland types.

Discussion

The DBI scores were the highest in PA sites and significantly different from those relating to the large sugarcane sites. This would be expected as species that are sensitive to disturbance have higher scores than resilient species and the protected area sites were selected on the basis that they were not affected by anthropogenic disturbances (Simaika and Samways 2009a). Simaika and Samways (2009b) used the DBI to prioritise sites for conservation purposes and suggest that partially protected sites such as the Kogelberg Biosphere Reserve have the highest value for the conservation of globally Red Listed taxa. Although no Red Listed species were sampled here, the higher DBI score for the PA sites shows that ecological integrity is being maintained at these sites in the Eston-Mid-Illovo area. Some pristine sites within the study area were fully protected from disturbance such as the Gwahumbe Reserve which has been accredited with Natural Heritage Site status. Sites further down the valley which were outside the borders of the reserve showed similar DBI scores which indicates that although these sites were not formally protected, they are still of significant conservation value.

The lowest DBI scores here were at the large sugarcane sites. Simaika and Samways (2009b) noted that in the Kruger National Park, which was the largest protected area in their study, has only one endemic species, yet the high species richness of the area highlighted its conservation value. Similarly, the large sugarcane sites here had the highest species richness, signifying their conservation value for the local Odonata fauna. Indeed, 28 of the 33 total species recorded here were found in these sites, with five species being confined to only the sugarcane area. DBI values at the forestry sites were second highest recorded for the four wetland groups. Forestry plantations in South Africa have been conserving biodiversity for a substantially longer amount of time than sugarcane areas, and accordingly these regulated forestry systems appear to be housing more localised and specialist species than the sugarcane systems (DWAF 2006; Samways and Steytler 1996).

The species were primarily distributed between sugarcane and the PA sites, with these two groups sharing 22 out of 33 total species, whilst forestry and PA sites supported 17 of the 33.

Furthermore, twice as many Zygoptera species were found in sugarcane sites compared to forestry sites reflecting the general preference for less shady sites as reflected by recovery of Zygoptera when alien invasive plants are removed (Samways and Sharratt 2010). Clark and Samways (1996) found that the number of Anisoptera and Zygoptera increased significantly with an increase in reed cover, which was the case here for sugarcane ponds which were largely surrounded by dense reed stands.

Dissolved oxygen values showed a positive statistically significant relationship with log DBI scores at my sites. Lower dissolved oxygen values are associated with increased eutrophication which may be caused by point pollution such as waste water or non-point pollution sources such as increased nutrients from fertilizers or field ploughing (e.g. Silva *et al*. 2010). Increasing eutrophication has been shown to alter the community structure of organisms (e.g. Pinto-Coelho 1998) and this appears to be the case here where the more sensitive Odonata species had an affinity for sites with lower eutrophic impact. However, Silva *et al*. (2010) caution discussion on the effect of water variables on abundant Odonata species as many species are able to disperse large distances to find ideal habitat whilst also being able to recolonize severely impacted areas (e.g. McPeek 1989). Alternatively, vegetation structure has more of an impact on Odonata diversity than water orientated variables (Foote and Hornung 2005). This could be used to account for the significant relationship between DBI and long grass cover, as many South African odonate species use grasses as perching sites (e.g. Samways and Taylor 2004).

The Eston-Mid-Illovo area is located within an intermediate zone between the coast and mountainous areas and accordingly Odonata which are suited to both environments were found at the various sites. Coastal Odonata preferred ponds in sugarcane catchment as all nine coastal species were found here including *T. limbata*, *U. assignata* and *R. semihyalina* which were only found in the sugarcane sites. This is possibly due to sugarcane primarily being a coastal crop in South Africa and these coastal Odonata have subsequently adapted to this local environment which resembles at least structurally many of the natural ponds and marshes farther north in KZN, and is preferred by them compared to forestry sites. Small sugarcane sites had higher DBI scores than the large sugarcane sites, however, species richness of Odonata was higher in large sugarcane sites compared to small sugarcane sites. This shows that small sites in the sugarcane mosaic may support complex biotopes with smaller more specialised sub-sites and thus have a higher conservation value compared with large sugarcane sites (e.g. Osborn and Samways 1996). Coastal species clearly favoured the sugarcane sites whilst montane species were spread out over all site types whilst showing some bias to sugarcane ponds. Sugarcane is by far the most dominant crop in the area and subsequently specialist forestry habitat is in low abundance. The low overall area of suitable habitat for forest Odonata species is the main reason that no unique species was found at these sites in this study.

Conclusions and recommendations for conservation

The use of the DBI in this study gave intriguing insight into the condition of ponds and general wetland areas of the various agricultural mosaics in KZN. This index showed that although species richness may be high (e. g. large sugarcane sites), a low DBI score points towards a problem of ecological integrity in a system. This chapter highlights the importance that PAs play in conserving localised and sensitive Odonata species as well as the role that ponds are playing as habitat islands for certain species in agricultural systems. Utilisation of the DBI requires an extensive record of Odonata species found at a particular locality and fortunately for South Africa a substantial database exists as well as a comprehensive field guide of the Odonata found in the country complete with DBI scores (Samways 2008; Simaika and Samways 2009a). Farmers in the Eston-Mid-Illovo area should make use of the DBI system, as the DBI is a user friendly and robust scoring system, to monitor their ponds and wetlands as an early warning protocol for eutrophic or even pesticide pollution, or alternatively in wetland restoration programmes (Simaika and Samways 2009a).

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Chapter 4

Conclusions and Recommendations

The increased intensity of agriculture on a global scale has caused widespread negative effects on natural biodiversity (Chamberlain *et al*. 2000). In order to offset these effects, agricultural activities are undergoing a shift towards sustainable practices which is echoed by the creation of the Aichi Targets (CBD 2011). In South Africa, and particularly KwaZulu-Natal (KZN), timber and sugarcane agriculture is very important to the economy. Sustainable practices are presently being enforced on forestry plantations and accordingly these plantations have adhered to FSC (Forestry Stewardship Council) international standards since the 1990's which promotes biodiversity friendly agriculture (FSC 1996; Samways *et al*. 2010). Alternatively, some sugarcane farmers in the country have only recently begun implementing sustainable Better Management Practices (BMPs) as a follow on from the Sustainable Sugarcane Farm Management System (SUSFARMS) initiative which also aims to minimise the damage that sugarcane agriculture is causing to the environment (Maher 2007).

In this study, the impact that timber and sugarcane agriculture has on indigenous insect and plant diversity within the respective plantations was assessed. To acquire the relevant information, ponds and reservoirs were visited and population data was collected on plants, aquatic Coleoptera and Odonata (Odonata is used to represent both of the dragonfly sub-orders: Anisoptera and Zygoptera, unless explicitly stated otherwise) in order to provide a summary of the biodiversity that is still found in these disturbed environments (Chapter 2). Furthermore, as Odonata are known to be indicators of habitat quality, I assessed the populations of these particular species in depth and scored them according to the Dragonfly Biotic Index (DBI) which allowed for more in depth knowledge about the ecological integrity of the various habitats (Simaika and Samways 2008, Simaika and Samways 2009; Chapter 3).

Wetlands in forestry sites had the highest overall species richness compared to sites in sugarcane plantations and even protected areas which contrasts the study by Bremer and Farley (2010) who found that plant diversity was higher in native plantations compared to exotic plantations. Proximity of wetlands to agriculture was a significant factor in determining plant species composition. The sugarcane sites exhibited the highest level of alien invasion, which was attributed to the high level of disturbance in these areas. Species richness of aquatic Coleoptera was low at all sites, however, data suggested that the time of year has a significant influence on the abundance of certain species. I found that the ponds in large sugarcane sites had the highest Odonata species richness when compared to sites in forestry agriculture and even sites within protected areas (Chapter 2). These Odonata do not necessarily need conservation action as they were primarily widespread species (Chapter 3), however, the role that these agricultural ponds are performing in terms of overall biodiversity conservation cannot be underestimated as they do provide habitat for some species (Briers and Biggs 2005; Pryke *et al*. 2015). The sugarcane wetlands were highly invaded by alien plants, yet, they still managed to support native Odonata populations. The study area is highly transformed for agricultural purposes and accordingly protected or natural habitats are not common. The forestry sites had lower species richness of Odonata than both large sugarcane sites and protected area sites, which was unexpected. However, these ponds still supported important endemic species that show preference to forested habitats therefore highlighting their conservation significance (Samways and Steytler 1996).

Although species richness of Odonata was highest in the large sugarcane sites, a closer inspection of the species assemblages revealed that these sites are primarily acting as a refuge for widespread generalist species with low conservation value (Chapter 3). Subsequently it is the protected area sites, with a slightly lower species richness than the large sugarcane sites that are the most important habitats for conserving Odonata in this area, especially given their significant higher DBI score. This highlights the underlying ecological integrity problem that is being experienced at large ponds and reservoirs within sugarcane mosaics. At small ponds in sugarcane sites, the lowest species richness of Odonata was found, however, the DBI scores of these sites were not significantly different from forestry or protected areas. This shows that these small sugarcane sites may have more complex biotopes, and accordingly more specialists, compared to the large sugarcane sites therefore indicating at least some conservation value of these sites (Osborn and Samways 1996). Ponds and reservoirs within agricultural systems do contribute substantially to the conservation of Odonata in this area as some species were only found at these sites and not in the surrounding protected areas. Protected areas in this study play a key role in conserving the native biota found in this region, particularly sensitive Odonata species and therefore the significance of these areas with regards to the conservation of biodiversity within agricultural mosaics cannot be underestimated (Pryke *et al.* 2015).

Conserving biodiversity within agricultural settings is divided into two broad approaches namely land sharing, where agricultural practices are altered to increase biodiversity within the immediate agricultural zone, and land sparing, where areas are left as uncultivated habitat (Green *et al*. 2005; Egan and Mortensen 2012). This study showed the importance of large scale PA's amongst the agricultural mosaic regarding the conservation of sensitive species (Chapter 3). If the land sharing approach was implemented on a large scale in the area, more of the PA's would need to be cultivated which would be detrimental to the biodiversity conservation in the area. Land sparing has been advocated for the conservation of native plants (Egan and Mortensen 2012), birds (Phalan *et al*. 2011) and dung beetles (Montoya-Molina *et al*. 2016), however, with the dung beetles, land sharing was noted as a good complementary conservation option together with land sparing. Phalan *et al*. (2011) also noted that land sparing would also minimise negative effects on overall food production which is a crucial factor considering the global population dynamics. The findings of this study clearly advocate land sparing as the primary conservation strategy for the south Midlands area which would, at the very least, slow the rate of biodiversity loss.

Management recommendations

It is clear from this study that agricultural ponds and reservoirs are important for the conservation of regional biodiversity. Farmers should be made aware of the contribution that the ponds are having with regard to aquatic insect conservation as this would likely influence them and other farmers in the area to conserve their wetland areas. The increased effort into the conservation of insects would also have knock-on effects resulting in other organisms returning to the area such as birds and mammals. Clearing of alien plants in the waterways and other wetland areas of farms would be an ideal way to initiate biodiversity conservation, as well as improve water quality and availability on farms, although this is a costly activity (Turpie *et al*. 2008). Lower dependence on fertilisers by farmers could also result in healthier systems and accordingly more specialist Odonata species in their wetland areas thus increasing the conservation value of the land (Chapter 3).

Farmers can and should utilise the DBI system to firstly assess and then monitor aquatic systems on their land as this system is user-friendly and robust (Simaika and Samways 2009). It can also be used as an early warning system for habitat degradation and alternatively to monitor the recovery of a system should farmers attempt to improve the state of their wetlands, as this study recommends (Samways and Taylor 2004). Farmers should also replenish their wetlands by planting indigenous sedges such as *Cyperus dives* which will increase the indigenous plant composition of the wetlands whilst also aiding in *Eldana saccharina* (stem borer) control (Conlong *et al*. 2007). The benefits of this Integrated Pest Management (IPM) strategy can also be shared across farm borders which will encourage more land owners to get involved. Ultimately, however, it is the individual efforts of farmers and landowners that will result in the conservation of all biodiversity in these agricultural systems.

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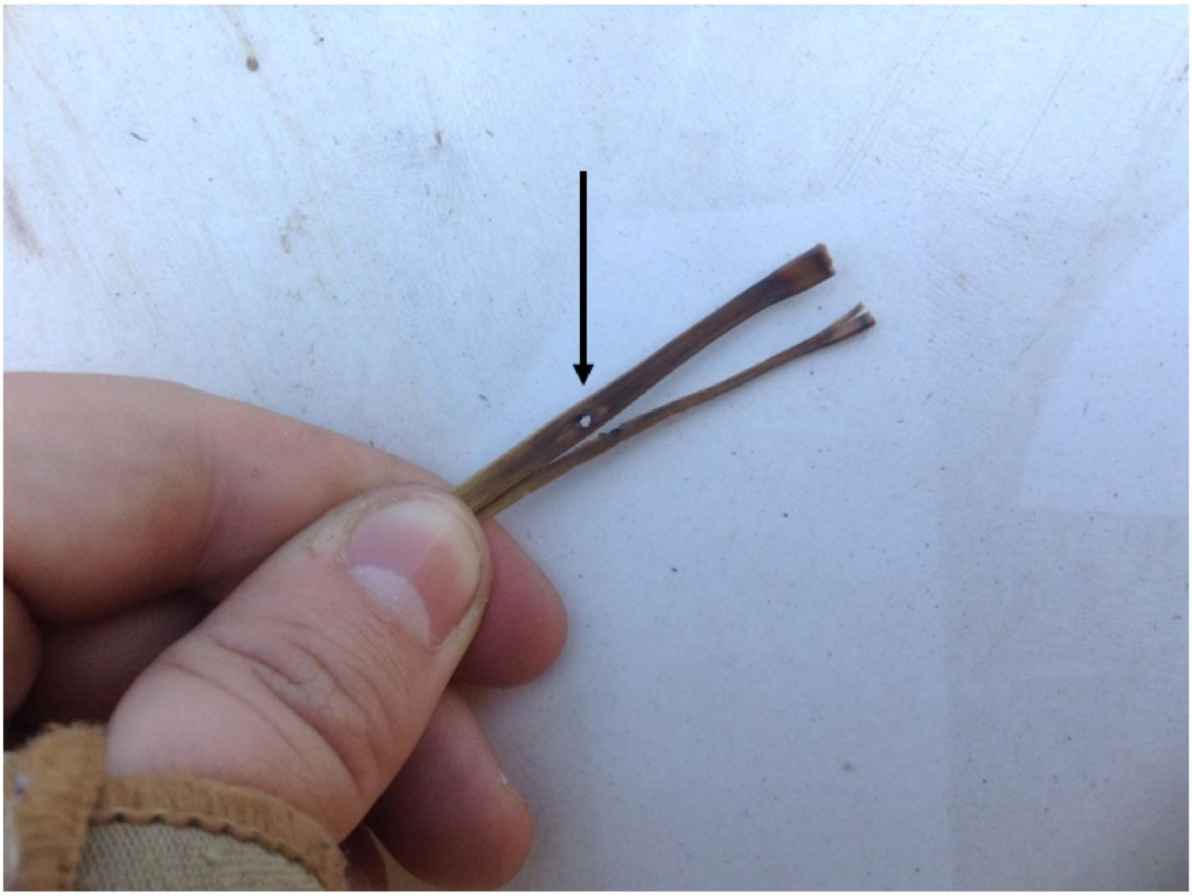
Appendix 1

Stem borer diversity within agricultural wetlands

Push-pull, a strategy for Integrated Pest Management, is a habitat management technique that manipulates insect pests via stimuli such as visual or chemical signals that make the protected habitat or resource unattractive to these pests (push) whilst also enticing them to a more attractive area (pull) (Cook *et al*. 2007). In the sugarcane growing areas of South Africa this technique uses natural wetlands to draw *Eldana saccharina* out of sugarcane crops and within these wetlands natural enemies such as parasitoids are able to prey on this pest (Conlong 1990).

A portion of my sampling time for this thesis was spent on collecting data on stem borer populations at the same sites where all the other data was collected. My aim was to gauge if stem borers are residing within indigenous host plants in the area, as individuals were being found within sugarcane stalks at the sites indicating their presence in the region (Pers. comm. P. Botha). Stem borer sampling has historically been a high-effort-low-reward field activity as larvae are generally found in low abundance in indigenous host plants (Gounou and Schulthess 2004). Here, I sampled 10 sedge stems and 50 grass stems at each of the 40 sites described in Chapters 2 and 3. Sampling occurred at ten sites in pristine areas (PAs), ten in forestry sites, ten in large sugarcane sites and ten in small sugarcane sites (Chapter2; Table. 2.1). To conduct the sampling, a suitable area at the site was chosen where stems and/or leaves are of the plants are damaged i.e. dead hearts (dead leaves at the apical growth point) and exit holes in the stems (Le Rü *et al.* 2006; Appendix 1 Fig. 1)

Sampling found very low incidences of stem borers in these wetland sites (Only five species were found which were all weevils or Coleoptera), therefore no statistical significance could be inferred. Interestingly one stem borer was found that was not known to be a potential sugarcane pest in the area, however, this is currently being reviewed at the South African Sugarcane Research Institution (SASRI) (Appendix 1 Fig. 2). No *E. saccharina* were found during this survey. This doesn’t mean that this area is not under threat. Rather it means that the high levels of wetland maintenance in this area might have contributed to the control of this pest species. Unfortunately I cannot substantiate this claim further as borer abundance was known to be low in this area compared to other areas of the province (Pers. comm. P. Botha). I feel that further studies should be done on the wetlands in this area as the stressed environment being experienced in 2015 due to drought has lead to a significant increase in borer abundance (Pers. Comm. P. Botha; South African Weather Service 2015). Kasl (2004) has shown that sugarcane fields with *Cyperus papyrus* L. (Cyperales: Cyperaceae) stands growing adjacently to them had significantly less crop damage, inflicted by *E. saccharina*, than fields which did not have *C. papyrus* growing adjacently. This illustrates that push-pull can be effective, however, overall good crop management practices need to be implemented to ensure the success of push-pull (Cockburn 2013). The maintenance of healthy wetlands may therefore contribute towards pest control, however, this added function of wetlands needs to be explored a great deal further (de Groot *et al*. 2002).



Appendix 1 Figure 1. An example of stem borer damage in grass (exit hole).

Appendix 1 Figure 2. A weevil (Curculionidae) found in Cyperus dives stems in the south-Midlands of KZN. This species is a new potential sugarcane pest discovered in a wetland zone amongst sugarcane agriculture (Lep 192. RSA. Site 17. 26/08/14. Andrew Briggs. From *C. dives* Lep 192 in sasri image library. Sex 2503).

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Appendix 2

Appendix 2 Table 1. List of all recorded species in this study including abundances, DBI scores (Odonata), threat status (available records) and species codes for use in PRIMER 6. LC=Least Concern, NE=Not Evaluated, VU=Vulnerable, EN=Endangered and CE=Critically Endangered (IUCN 2008).

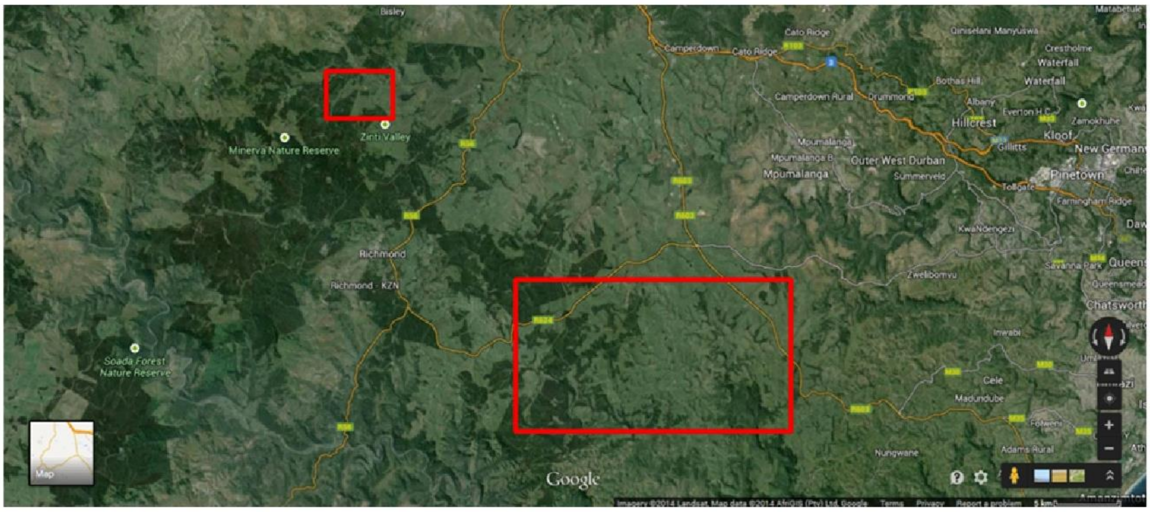
Order	Sub-order	Family	Species	Code	Abundance	DBI	Threat status
Odonata	**Anispotera**	**Aeshnidae**	*Aeshna minuscula* (McLachlan, 1896)	DAm	5	5	-
			Aeshna subpupillata (McLachlan, 1896)	DAsu	7	4	-
			Anax imperator (Leach, 1815)	DAi	189	1	LC
			Anax speratus (Hagen, 1867)	DAsp	72	2	LC
		Gomphidae	*Ceratogomphus pictus* (Hagen in Selys, 1854)	DCp	21	2	LC
			Notogomphus praetorius (Selys, 1878)	DNp	53	5	LC
			Paragomphus cognatus (Rambur, 1842)	DPco	12	1	LC
		Libellulidae	*Crocothemis erythraea* (Brullé, 1832)	DCe	133	0	LC
			Crocothemis sanguinolenta (Burmeister, 1839)	DCs	62	3	LC
			Nesciothemis farinosa (Förster, 1898)	DNf	201	1	LC
			Orthetrum caffrum (Burmeister, 1839)	DOc	90	3	LC
			Orthetrum julia falsum (Longfield, 1955)	DOj	162	1	LC
			Pantala flavescens (Fabricius, 1798)	DPf	21	0	LC
			Rhyothemis semihyalina (Desjardins, 1832)	DRs	17	1	LC
			Sympetrum fonscolombii (Selys, 1840)	DSf	32	0	LC
			Tramea limbata (Desjardins, 1832)	DTl	27	0	LC
			Trithemis arteriosa (Burmeister, 1839)	DTa	5	0	LC
			Trithemis furva (Karsch, 1899)	DTf	176	0	LC
			Trithemis stictica (Burmeister, 1839)	DTs	193	1	LC
			Urothemis assignata (Selys, 1872)	DUa	15	3	LC

	Zygoptera	**Chlorocyph-idae**	*Africallagma glaucum* (Burmeister, 1839)	DAg	39	1	LC
			Azuragrion nigridorsum (Selys, 1876)	DAn	109	3	LC
			Ceriagrion glabrum (Burmeister, 1839)	DCg	205	0	LC
			Ischnura senegalensis (Rambur, 1842)	DIs	142	0	LC
			Platycypha caligata (Selys, 1853)	DPca	77	2	LC
			Pseudagrion citricola (Barnard, 1937)	DPci	8	3	LC
			Pseudagrion hageni tropicanum (Karsch, 1893)	DPht	105	2	LC
		Coenagrioni-dae	*Pseudagrion kersteni* (Gerstäcker, 1869)	DPk	482	1	LC
			Pseudagrion salisburyense (Ris, 1921)	DPs	83	1	LC
		Lestidae	*Lestes plagiatus* (Burmeister, 1839)	DLp	1	2	LC
		Platycnemid-idae	*Allocnemis leucosticta* (Selys, 1863)	DAl	100	5	LC
		Protoneuridae	*Ellatoneura glauca* (Selys, 1860)	DEg	178	1	
		Synlestidae	*Chlorolestes tessellatus* (Burmeister, 1839)	DCt	131	4	LC
Coleoptera	**Adephaga**	**Dytiscidae**	Africophilus (Guignot, 1948) sp. 1	BAF1	1		-
			Hydaticus (Leach, 1817) sp. 1	BHYDA1	10		-
			Hydaticus (Leach, 1817) sp. 2	BHYDA2	3		-
			Hydaticus (Leach, 1817) sp. 3	BHYDA3	3		-
			Hydaticus (Leach, 1817) sp. 4	BHYDA4	4		-
			Hyphydrus (Illiger, 1802) sp. 1	BHYPH1	11		-
			Hyphydrus (Illiger, 1802) sp. 2	BHYPH2	1		-
			Hyphydrus (Illiger, 1802) sp. 3	BHYPH3	1		-
			Hyphydrus (Illiger, 1802) sp. 4	BHYPH4	14		-
			Laccophilus (Leach, 1815) sp. 1	BLA1	9		-
			Laccophilus (Leach, 1815) sp. 2	BLA2	9		-
			Philaccolus (Guignot, 1937) sp. 1	BPHILA1	6		-
			Philodytes (Balfour-Browne, 1939) sp. 1	BPHILO1	1		-
			Philodytes (Balfour-Browne, 1939) sp. 2	BPHILO2	3		-

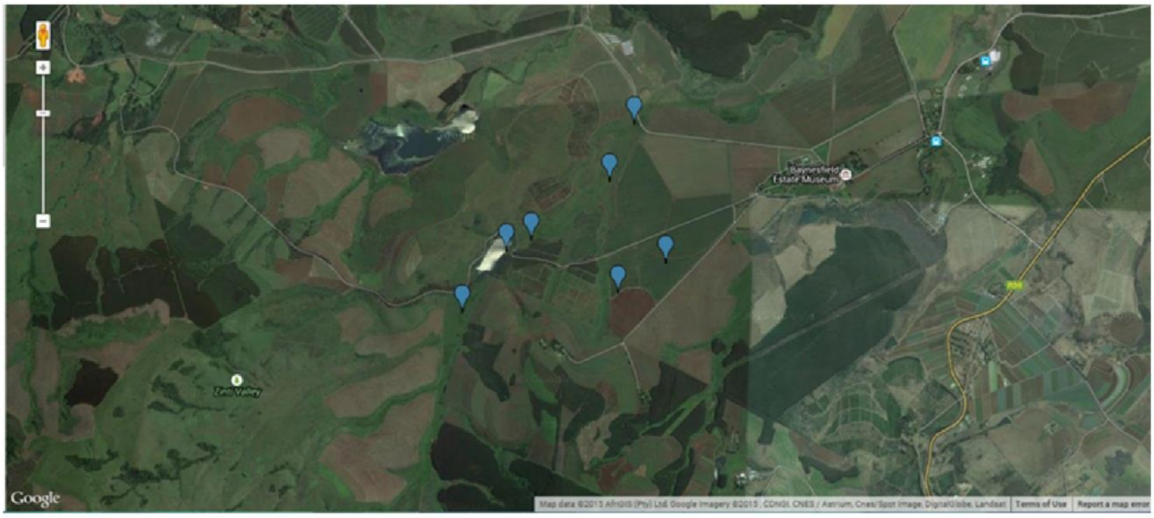
	Gyrinidae	Dineutus (Macleay, 1825) sp. 1	BDN1	53	-
		Gyrinus (Geoffroy, 1762) sp. 1	BGY1	29	-
		Orectogyrus (Régimbart, 1884) sp. 1	BOR1	325	-
	Haliplidae	Haliplus (Latreille, 1802) sp. 1	BHAL I1	8	-
		Haliplus (Latreille, 1802) sp. 2	BHAL I2	20	-
	Hydrochidae	Hydrochus (Leach, 1817) sp. 1	BHY DR1	5	-
	Hydrophilidae	Amphiops (Erichson, 1843) sp. 1	BAM 1	4	-
		Amphiops (Erichson, 1843) sp. 2	BAM 2	1	-
Asparagales		Kniphofia Moench sp. 1	P36	24	-
Asterales		*Ageratina adenophora* Spreng.	P10	32	NE
		Asteracea Bercht. & J.Presl sp. 1	P31	16	-
		Asteracea Bercht. & J.Presl sp. 2	P24	19	-
		Asteracea Bercht. & J.Presl sp. 3	P34	32	-
		Berkheya erysithales (DC.) Roessler	P26	15	LC
		Bidens pilosa L.	P25	61	NE
		Conyza floribunda Kunth	P3	51	NE
		Helichrysum Mill. sp. 1	P22	4	LC
		Senecio burchellii De Candolle	P23	61	LC
Caryophyllales	**Phytolaccaceae**	*Rivina humilis* L.	P40	29	NE
Lamiales	**Verbenaceae**	*Verbena bonariensis* L.	P16	75	NE
Poales	**Cyperaceae**	*Cyperus congestus* Vahl	P21	289	LC
		Cyperus dives Delile	P39	79	LC
		Cyperus esculentus L.	P5	406	LC
		Cyperus involucratus Rottb.	P35	31	LC
		Cyperus textilis Thunb.	P43	51	LC
		Isolepis prolifera (Rottb.) R.Br.	P19	177	LC
	Poaceae	*Aristida junciformis* Trin. et Rupr.	P8	77	LC
		Arundinella nepalensis Trin.	P14	43	LC
		Chloris gayana Kunth	P11	106	LC
		Cymbopogon validus (Stapf) Burtt Davy	P17	33	LC
		Eragrostis Wolf sp. 1	P42	3	LC

		Helictotrichon Besser sp. 1	P41	35	LC
		Hyparrhenia cymbaria (L.) Stapf	P6	32	LC
		Ischaemum fasciculatum Brongn.	P30	38	LC
		Panicum maximum Jacq. var. hirsutissimum (Steud.) Oliv.	P28	44	LC
		Paspalum notatum Flüggé	P38	41	NE
		Paspalum urvillei Steud.	P2	114	NE
		Pennisetum clandestinum Hochst. ex Chiov.	P44	93	NE
		Phragmites australis (Cav.) Trin. ex Steud	P20	237	LC
		Setaria megaphylla (Steud) Dur. & Schinz.	P27	146	LC
		Setaria sphacelata (Schumach.) Stapf & C.E.Hubb. ex M.B.Moss	P1	211	LC
		Sorghum halepense (L.) Pers.	P37	19	NE
		Sporobolus africanus (Poir.) Robyns & Tournay	P13	109	LC
		Sporobolus fimbriatus (Trin.) Nees	P9	32	LC
		Sporobolus ioclados (Trin.) Nees	P4	48	LC
		Themeda triandra Forssk.	P15	49	LC
		Urochloa panicoides P.Beauv.	P29	13	LC
	Typhaceae	*Typha capensis* (Rohrb.) N.E. Br.	P18	384	LC
Polypodiales	**Lomariopsidaceae**	*Nephrolepis exaltata* (L.) Schott	P33	141	NE
Rosales	**Rosaceae**	*Rubus fruticosus* L.	P12	309	NE
Salviniales	**Salviniaceae**	*Salvinia molesta* D.Mitch.	P32	103	NE

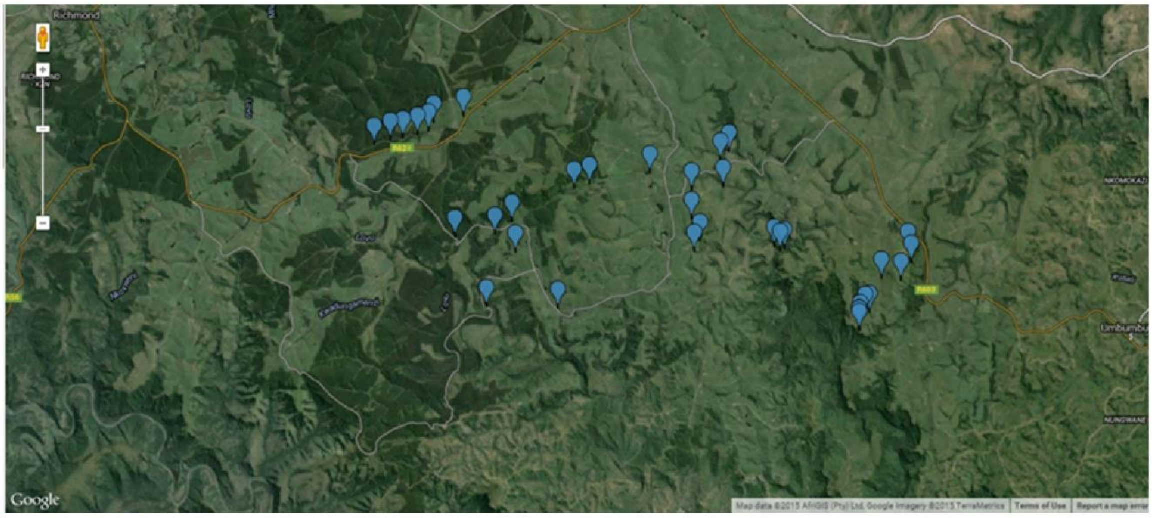
Appendix 3



Appendix 3 Figure 1. This is an aerial image showing the study area in its entirety. The red square on the bottom of the image represents the Eston (29° 52' 8.72"S; 30° 32' 0.43"E) and Mid-Illovo (29° 57' 58.19" S; 30° 30' 55.63" E) study areas whilst the red square at the top of the image represents the Baynesfield study area (29° 45' 52.06"S; 30° 20' 22.37"E).



Appendix 3 Figure 2. This is an enlarged aerial image of the Baynesfield study area (29° 45' 52.06"S; 30° 20' 22.37"E) (top left square from appendix figure 5.3). The actual sites where sampling took place are represented by the blue flags.



Appendix 3 Figure 3. This is an enlarged aerial image of the Eston (29° 52’ 8.72”S; 30° 32’ 0.43”E) and Mid-Illovo (29° 57’ 58.19” S; 30° 30’ 55.63” E) study areas (bottom right square from appendix figure 5.3). The actual sites where sampling took place are represented by the blue flags.

Appendix 3 Figure 4. This image shows the areas of sugarcane operation in South Africa highlighted in lime green (rain fed areas) and light blue (irrigated areas), with all sugar mills in the country highlighted in red. Image courtesy of SASA (2015b).

Appendix 4

Appendix 4 Figure 1. An example of a large sugarcane (BC) site near to Mid-Illovo (29° 58' 32.21" S; 30° 38' 23.81" E). The plants in the foreground are primarily *Typha capensis* (Rohrb.) N.E. Br. (Poales: Typhaceae) and *Nephrolepis exaltata* (L.) Schott (Polypodiales: Lomariopsidaceae) species.

Appendix 4 Figure 2. An example of a small sugarcane (SC) site near to Mid-Illovo (29° 53' 39.46" S; 30° 28' 23.79" E). This particular pond was completely surrounded by *Cyperus esculentus* L. (Poales: Cyperaceae) individuals.

Appendix 4 Figure 3. An example of a forestry (FOR) site near to Mid-Illovo (29° 56' 8.12'' S; 30° 28' 41.59'' E). The plants in the foreground here are primarily *Typha capensis* (Rohrb.) N.E. Br. (Poales: Typhaceae) individuals.

Appendix 4 Figure 4. An example of a protected area (PA) site near to Mid-Illovo (29° 59' 2.81" S; 30° 35' 35.09" E). The plants in the foreground here are *Setaria megaphylla* (Steud) Dur. & Schinz. (Poales: Poaceae) Individuals.

Appendix 4 Figure 5. A Sign outside Hope Valley Nature Reserve (29° 57' 24.64" S; 30° 33' 46.56" E), a section of Gwahumbe Reserve, showing the heritage site status. Data for PA sites was collected within areas such as this.