UNIVERSITY OF CAPE COAST

THE EFFECTS OF HABITAT DISTURBANCE ON ADULT ODONATA ASSEMBLAGES IN URBAN FRESHWATER HABITATS OF SOUTHERN CAPE COAST METROPOLIS OF GHANA

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BY

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Thesis submitted to the Department of Conservation Biology and Entomology of the School of Biological Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Entomology

NOVEMBER, 2022

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature …………………………… Date ……………………...

Name ………………………………………………………………

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidance on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's signature ……………………

Date …………………….

Name: ………………………………………………………………

Co-Supervisor's Signature ………………………….

Date ……………………

Name: ………………………………………………………………

ABSTRACT

Members of the insect Order Odonata have been widely used as indicators of the integrity of freshwater ecosystems. However, the effects of anthropogenically induced factors continue to affect their assemblages especially in urban areas. As such, this study was conducted to investigate the influence of human and natural habitat conditions on Odonate assemblages in freshwater habitats of southern Cape Coast Metropolis in the Central Region of Ghana. This was important to address the existing gap in knowledge on the Odonata species within the Metropolis and consequently, the effects of urban habitat conditions on Odonate assemblages in a tropical ecosystem. A total of four sampling visits per each of the 16 sites used for the study from January to June 2022, provided data on Odonata species. A habitat integrity index was generated for each site and used to categorise sites into 3 levels of disturbance: high, moderate, and least. Local climatic variables were measured and recorded for each study site. Twenty-six species of dragonflies and damselflies were recorded within the Metropolis. Generalised mixed effect model showed a varying significant effect of pH, water retention mechanism, condition of the riparian vegetation, preservation of the riparian vegetation and the presence or absence of cropland on dragonfly and damselfly abundance, diversity and compositions. A dragonfly biotic index was developed for habitat quality assessment within the Metropolis which showed that freshwater habitats within the Metropolis are experiencing some level of disturbance. There is therefore the need for conservation efforts to restore the integrity of the habitats surveyed and the entire Metropolis and the success of these actions can be monitored using the DBI.

KEYWORDS

Odonata

Dragonfly

Damselfly

Freshwater

Urbanisation

Habitat Disturbance

Bioindicator

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DEDICATION

To my Family

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CHAPTER ONE

INTRODUCTION

The insect order Odonata (dragonflies and damselflies) are an important group of insects that play significant roles in the ecosystem. Dragonflies and damselflies occupy the highest niche in a food web, acting as obligate predators. They feed on several aquatic and terrestrial insects at the larval and adult stages (Corbet, 1980). They are also able to detect very small changes in freshwater ecosystems and hence have been used as indicators of healthy ecosystems. Despite the significant roles odonates play, they continue to be threatened mainly due to anthropogenic activities which directly and indirectly alter the condition of habitats within which they live (Lososová *et al*., 2012; Sol *et al.*, 2014). As global urbanisation increases, anthropogenic activities increase and have the potential to quickly change the biodiversity composition in an area within a short period due to the rapid change in habitat. One of the significant impacts of urbanisation is the loss of biodiversity and as such efforts are needed to minimise the impacts of urbanisation and to promote conservation. The Odonata are good model organisms for assessing the impacts of urbanisation on biodiversity (Clark & Samways, 1996; De Carvalho *et al.*, 2013; Monteiro-Júnior *et al.*, 2014; Monteiro Júnior *et al*., 2015). It is therefore important that surveys of Odonata are conducted periodically to monitor species status especially in areas where limited data exist. Combining Odonata surveys with environmental assessments would provide the needed information on the extent of the impacts of urbanisation on Odonate assemblages.

Background of the Study

Freshwater systems provide several essential services to humans, which includes its importance as a source of water for drinking, energy generation and irrigation. Freshwater systems are not only beneficial to humans but also to wildlife and biodiversity, and serve as a habitat for over 40% of fisheries resources as well as one-fourth of vertebrate diversity globally (Lundberg *et al.*, 2010). Freshwater systems, which include rivers, lakes, ponds, wetlands, streams, reservoirs and groundwater, also harbour approximately 6% of globally known species (Dudgeon *et al.*, 2006). Even though freshwater systems are important, they continue to be degraded and threatened (Dudgeon *et al.*, 2006; Turak *et al.*, 2017).

Majority of threats and causes of freshwater degradation are human-induced (Dodds *et al.*, 2013; Schmeller *et al.*, 2018; Mangadze *et al.*, 2019; Van Soesbergen *et al.*, 2019), with land use change and pollution playing significant roles (Muñoz-Villers & López-Blanco, 2008; Butchart *et al.*, 2010; Monteiro Júnior *et al.*, 2015; Cunha *et al.*, 2019). Urbanisation, which is associated with the alteration of natural landscapes, change in microclimatic conditions, and an increase in pollution beyond degradable levels (Grimm *et al.*, 2008; McDonald, 2008), has been identified to be a key driver of ecosystem change. Urbanisation continues to alter ecosystems and the natural environment at an increased rate. More than half of the world's population currently live in urban areas (Grimm *et al.*, 2008), and this number has been predicted to reach 60% before the year 2025 (Güneralp & Seto, 2013; Seto *et al.*, 2012). Increasing human activities and land uses due to urbanisation have negative impact on biodiversity and the conditions of the natural environment. Urbanisation has the potential to alter biodiversity composition and to some extent lead to homogenisation of species through a replacement of non-urban specialist species, with species known to have wider habitat ranges and are capable of exploiting wider resources, and are more adapted to urban habitats (Lososová *et al*., 2012; Sol *et al*., 2014). Urban environments also create a regional climate change effect known as the "Urban Heat Island" (Grimm *et al*., 2008) thereby increasing overall temperature in terrestrial areas and surface water, which significantly affects biodiversity. Temperature for instance, is known to affect odonate phenology (Hassall *et al*., 2007), polymorph frequency (Gosden *et al*., 2011), and body size (Hassall, 2013, 2014).

Freshwater systems, aside the benefits they offer, also provide evidence for the health status of the terrestrial environment especially in urban areas. Several human activities in urban systems including construction of physical barriers to water flow, filling and draining of shallow water bodies, pesticide use, industrial and municipal waste and sewages, as well as destructive land use practices such as deforestation result in several changes to the condition of freshwater habitats (Combes, 2003).

Given the rapid growth of urban development and the associated impacts on biodiversity, it is crucial that an understanding of the implications for biodiversity is provided. To determine this impact on biodiversity, the biodiversity resources present within an area must be assessed over time to observe changing patterns both on a spatial and temporal scale in relation to the changing environmental variables within the area. An assessment of biodiversity within an urban area as well as the changing environmental variables are necessary to understand the implications of urbanisation on biodiversity.

The Odonata (dragonflies and damselflies) provide a good basis for understanding the impact of urbanisation on freshwater systems, the environment and biodiversity. This is so because they are both terrestrial and aquatic, as nymphs and adults. Odonata are also known to show high sensitivity at the species level to different habitat requirements (Simaika & Samways, 2009) and anthropogenic stressors (Hassall, 2015), hence they provide a basis for the understanding of a range of variables that characterise freshwater habitats, type and quality (Simaika *et al*., 2016). Some species of Odonata have lower abilities for dispersal hence they spend most of their lifecycle restricted to more pristine areas and less disturbed areas such as forests. These species are often referred to as habitat specialists. Generalists on the other hand have high ability for dispersal and are able to inhabit a wide variety of habitat types including disturbed areas and urban settlements (Clark & Samways, 1996; Samways & Steytler, 1996; Silva *et al*., 2010). Odonate communities and assemblages therefore reflect different types of habitats (Clark & Samways, 1996; Monteiro Júnior *et* al., 2013; Samways & Steytler, 1996; Wildermuth, 2010).

As such, Odonata diversities and abundance are specific measures for assessing the quality of habitats in both terrestrial and aquatic environments (Clark & Samways, 1996; Corbet, 1999). Adult diversity for instance reflect a change in the structure of riparian vegetation around freshwater habitats based on which adult Odonata have been used as indicators of riparian vegetation conditions of freshwater habitats (Clark & Samways, 1996; Carvalho *et al*., 2013; Monteiro-Júnior *et al*., 2014; Monteiro Júnior *et al*., 2015; Simaika & Samways, 2009). Odonata are also important because of their role as umbrella or flagship species. They show similarity in diversity and distribution with other freshwater species (Darwall *et al*., 2011) and also with birds (Tushabe *et al.*, 2006). As such, conservation policies and actions that are targeted at conserving biodiversity especially in aquatic habitats have focused on dragonflies and damselflies as conservation tools (Darwall *et al*., 2011; Dijkstra *et al*., 2011; Simaika *et al*., 2013).

Statement of the Problem

Dragonflies and Damselflies (Odonata) are undoubtedly a key group of organisms which are important as bioindicators of healthy ecosystems due to their ability to detect small changes within aquatic ecosystems. The Odonata are also one of the oldest groups of living insects and have survived several changes within ecosystems over time (Stoks & Cordoba-Aguilar, 2012; Bybee *et al*., 2016). However, there are gaps in knowledge of their distributions globally (Sandall *et al*., 2022). Knowledge on Odonate distributions is important for a better understanding of the group and to support the development of "Species Distribution Essential Variables" (Jetz *et al*., 2019) , especially because of frequent changes to their natural habitats (Christopher Hassall, 2015; Nagy *et al*., 2019). Despite the heterogenous nature of habitats globally, majority of assessments of Odonata occurrence have focused on forest areas with few studies in urban areas. In Ghana for instance, studies on Odonata have focused on their diversity, abundance and distribution as well as impacts of environmental variables on their diversity and distribution in forest reserves (Kyerematen *et al*., 2014; Seidu *et al*., 2017, 2019, 2020), farmlands (Acquah-

Lamptey *et al*., 2013a; Seidu *et al*., 2018), and small human settlements (Acquah-Lamptey *et al*., 2013a; Seidu *et al*., 2018).

A number of studies have successfully utilised dragonflies as indicators of the state of quality of aquatic systems (Oertli, 2008), and as indicators of ecological integrity (Samways & Taylor, 2004; Smith *et al*., 2007; Simaika & Samways, 2008, 2009; Silva *et al*., 2010), climate change (Bush *et al*., 2013; Hassall & Thompson, 2008), and anthropogenic effects (Catling, 2005; Foote & Hornung, 2005). Following the use of Odonata as bioindicators, the Odonates have been used to assess overall impact of urbanisation on biodiversity (Craves & O'Brien, 2013; Goertzen & Suhling, 2013; Villalobos-Jiménez *et al*., 2016; Wildermuth, 2010; Willigalla & Fartmann, 2012). A review of urban Odonata (Villalobos-Jiménez *et al*., 2016) show a growing body of literature on the impact of urbanisation and changes in habitat conditions on Odonata in urban areas but majority of these studies were conducted in the Americas, Europe and Asia. In Africa, very few studies relating to urban Odonata have been conducted and these studies were conducted in South Africa (Deacon & Samways, 2021; Villalobos-Jiménez *et al*., 2016).

Cape Coast Metropolis is one of the several Metropolis in Ghana. Located in the Central Region, the Metropolis is known to have hosted the first capital of Ghana. The Metropolis presents a unique coastal urban ecosystem which is known to inhabit several biodiverse resources, both flora and fauna (Deikumah & Kudom, 2010). A recent study using remotely sensed satellite images from 1990 to 2020 has shown the rapid conversion of natural areas within the Metropolis into urban settlements (Afrifa *et al*., 2022). Despite this, little is known about the species of Odonata within Cape Coast Metropolis. The only mention of an Odonata species in published literature within the area dates back to 1871 when *Phyllomacromia sophia* was identified as the earliest holotype (Dijkstra, 2007). As such, a study that is targeted at bridging the gap in information on impacts of urban habitat condition on Odonata is necessary. Findings of such a study would contribute to knowledge of species distribution which is important for protection of habitats.

Research Questions

1. What species of Odonata are present in different freshwater habitats in the Cape Coast Metropolis?
2. What are the effects of different freshwater habitat conditions on dragonflies and damselflies in the Cape Coast Metropolis?
3. How can dragonflies and damselflies be used to assess the integrity of freshwater habitats in the Cape Coast Metropolis?
4. What management efforts are required to protect freshwater habitats and Odonata that depend on them in the Metropolis?

Research Objectives

This study sought to assess the effect of habitat condition on adult Odonate assemblages in freshwater habitats within the Cape Coast Metropolis.

Specifically, the following objectives were set for the study, namely to;

1. Collect and document Odonata (dragonflies and damselflies) diversities and abundance in freshwater habitats within the Cape Coast Metropolis.
2. Assess the effects of habitat disturbance on Odonate assemblages in freshwater habitats located in the Cape Coast Metropolis.
3. Develop a local based Dragonfly Biotic Index to assess the integrity of freshwater habitats in the Cape Coast Metropolis.

Hypotheses

1. Abundance and diversities of Odonata are similar in different freshwater habitats within the Cape Coast Metropolis.
2. The condition of freshwater habitat has no effect on Odonate assemblages in different freshwater habitats within the Cape Coast Metropolis.

Significance of the Study

The study would provide information on Odonata species that benefit or are disadvantaged because of urbanisation. From the gaps identified in literature, this study seeks to provide latest information on Odonate assemblages specifically the diversities and abundance within an urban area especially in Ghana where little is known. This would provide information on the impact of urbanisation on Odonata diversities as compared to their diversities in natural environments. Information that would be obtained from this study would contribute to the documentation of dragonfly and damselfly species within the Cape Coast Metropolis and in Ghana. The study would also identify key environmental variables that impact Odonate assemblages in an urban area and would be the basis for the development of a local based Dragonfly Biotic Index (DBI) which can be used for assessing the quality of freshwater habitats in the Cape Coast Metropolis.

Findings from this study would provide information on the needs of Odonata species in urban systems which can serve as a baseline data for their conservation at the local scale and even on a regional scale (Kietzka *et al*., 2018). The findings would also provide information on the status of the health of freshwater systems within the Cape Coast Metropolis as well as their ability to support life of aquatic organisms and other organisms that depend on them.

It would also give an overall indication of the ecological health status of the Cape Coast Metropolis. This would inform policy decisions on protecting freshwater systems and for the overall conservation of freshwater systems in Cape Coast and the country at large.

Delimitations

The study presents detailed findings on the species of adult Odonata surveyed within the Cape Coast Metropolis in the Central Region of Ghana as well as how human activities affect the diversities and abundance of Odonata. The study focused on the diversities of only adult Odonata and as such larvae and tenerals were not surveyed in this study. The study was conducted during the day between the periods of 09:00 and 15:00 GMT only and there were no dawn or dusk surveys. Even though freshwater habitats were the focus of the study, a site along a lagoon, which is a brackish water system, was included. This was done because preliminary studies showed presence of adult Odonata along the lagoon and also to capture the correct extent of occurrence of the species as they occur in the Metropolis.

Limitations

The absence of dawn or dusk surveys may have influenced the species that were identified in this study as certain species are known to be predominantly active during those times. However, it must be noted that conducting surveys during the day has been actively used in several studies and has been recommended for assessments of this nature (eg. Costa Bastos *et al*., 2021; Christopher Hassall, 2015; Seidu *et al*., 2018). As such, the quality of the study was not compromised in any way. Also, the study proposed to assess the quality of water at Odonata habitats by measuring dissolved oxygen, electrical conductivity, and total dissolved solutes. Equipment was ordered for this measurement but they were lost in mail, as such these parameters could not be measured. Attempts to use equipment from other Laboratories proved futile. The parameters assessed in this study (Habitat integrity, temperature, windspeed, humidity, windspeed, water temperature, pH, light intensity) however give an excellent basis for drawing conclusions from the objectives of the study and the omission of those parameters does not affect the quality of the results in anyway.

Organisation of the Study

The thesis write-up is presented in six chapters; an introduction, a review of literature, the method used to achieve the objectives of the study, the results observed and the discussions thereof, as well as the summaries and conclusions drawn from the findings. The first chapter, which is the introduction presents the problem under study, by giving a background to the problem and clearly stating the objectives and questions that are to be answered. The significance of the study, delimitations, limitations and the organisation of the study is also presented in the first chapter. The second chapter provides current knowledge on the topic under study as reported by various studies. Current knowledge has been structured under different sub-headings to provide a thematic presentation of information related to each of the three objectives that have been set for this study. Chapter three details the methods that were adopted to answer the questions to be answered by the study. The study area, protocols adopted and data analysis have all been outlined in the third chapter. The findings of the study and inferences drawn from data collected as well as how the findings relate to other studies are all captured in the fourth and fifth chapters respectively. In the last chapter, summaries and conclusions drawn from the findings of the study, as well as recommendations based on the findings are presented.

CHAPTER TWO

LITERATURE REVIEW

This chapter presents a review of literature that are related to this study. The findings of the identified literature are reported, critiqued and the gaps identified outlined. To understand the insect group under study, the chapter presents known information on the biology of Odonata which includes their description and life cycle as well as the significant roles the Odonata play in ecosystems. Information on Odonata in Ghana are also presented and finally, information on known urbanisation impacts on Odonata, drawn from the impacts of biotic and abiotic factors as well as water quality factors on Odonate assemblages, are also presented.

Biology of Odonata

Description of Odonata

The Odonata are actively flying large and brightly coloured insects seen mostly flying above or near freshwater habitats. The order comprises of about 7000 to 7500 species (Dijkstra *et al.*, 2013) belonging to 3 suborders; Anisozygoptera (comprise two known species) (Corbet, 1980), Zygoptera (damselflies) and Anisoptera (dragonflies). The suborder Zygoptera is known to contain about 2941 species, while the suborder Anisoptera contains approximately 3,011 species (Dijkstra *et al.*, 2013), all belonging to 30 families (Anisozygoptera – 1, Zygoptera – 18, Anisoptera – 11) (Dijkstra *et al.*, 2013). In Africa, two suborders are predominantly present; Anisoptera and Zygoptera with 7 and 9 families present respectively (ADDO, 2016).

Adult Odonata are charismatic and easily recognised in their habitats due to their very pronounced features and varying colorations. The head of

Odonata bears large compound eyes that are easily seen and chewing mouthparts with strong jaws (Figure 1). The thorax is also vigorous and bears a forward-facing leg, which enables easy catching of prey both in flight and when perching as well as two pairs of glassy and translucent (hyaline) membranous wings. Suborders of Odonata can be identified by the positioning of their wings at rest. The Anisoptera opens its wings at rest (Figure 1a) while the Zygoptera lands with wings at the back (Figure 1b) (Pimenta & Pelli, 2019).

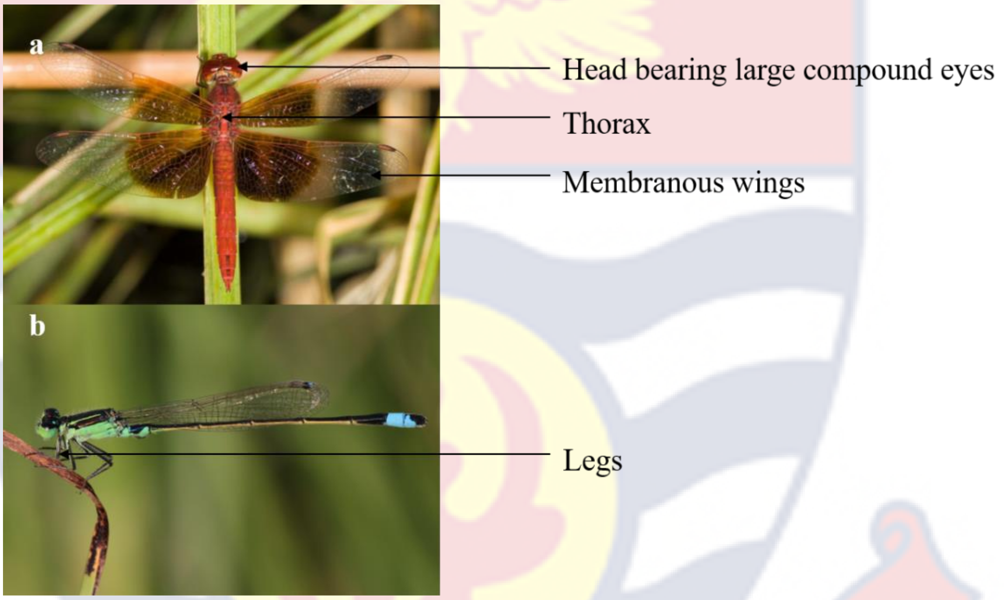

Figure 1: General characteristics of dragonflies (a) and damselflies (b) showing key features of the Odonata body.

Life Cycle of Odonata

Odonata life cycle involves three main stages: egg, larvae and adult. Odonata inhabit freshwater systems including ponds, rivers, streams, wetlands, pools of water and water seepages, among others. Adults visually detect cues for habitat selection especially for egg laying. Example of visual cues include the attraction of female adults to shiny water surfaces as a result of the reflection of light (Horváth *et al*., 1998; Bernáth *et al*., 2002), and the degree of polarization of reflected light to choose between dark or bright ponds as observed for species of the Orthertrum genera (Bernáth *et al.*, 2002).

Cues for habitat selection may also be non-visual which includes the use of flow rate of running water in Calopteryx species (Gibbons & Pain, 1992), the use of mechanoreceptors in ovipositor to evaluate stiffness of plants (Rebora *et al.*, 2013) in endophytic species such as *Lestes sponsa* and *L. barbarous* (Matushkina & Lambret, 2011) and *Aeshna cyanea* (Matushkina *et al.*, 2016). Other endophytic species such as *Aeshna cyanea* and *Ischhnura elegans* use gustatory sensilla to assess plant tissues before egg laying (Rebora *et al.*, 2013). The antennae of some Odonata species have also been found to possess olfactory and thermo-hygroreceptors (Frati *et al.*, 2016), which play important roles in habitat selection.

Female adult Odonata exhibit two main modes of oviposition, which vary between and within species; endophytic, where eggs are laid in plant tissues or similar materials (Bick *et al.*, 1976; Crumpton, 1975) and exophytic, where eggs are released above or upon a surface. Exophytic species may just drop egg from above (Corbet, 1980), release egg while tapping the water (Corbet, 1980) or scoop up drops of water with the tip of the abdomen (Williams, 1977). Other species release eggs equipped with grappling devices (Ando, 1962; Corbet, 1977).

The average number of eggs laid per time has been recorded to be between 100 to 400 eggs in Zygoptera (Bick *et al.*, 1976; Johnson, 1966) and between 100 to 1000 eggs in Anisoptera (Boehms, 1971; Corbet, 1962; Miyakawa, 1967). The duration of the egg stage has been found to last between 5 to 40 days (from laying to time of hatching (Corbet, 1980). The rate of egg development may be influenced by one or more of pre-diapause, diapause, and post-diapause, in response to varying temperatures (Boehms, 1971) and is also influenced by photoperiod (Corbet, 1980). The duration of the larval stage in Odonata is influenced by temperature and photoperiod with food availability as an additional factor.

The adult stage of Odonata takes place in two distinct periods: the pre-reproductive stage and the reproductive stage. The pre-reproductive stage also known as the maturation period, occurs between adult emergence and sexual maturity. At this stage, adults are sexually immature and undergo changes in body shape and size (Adetunji & Parr, 1974; Bilek, 1962; Johnson, 1973), wing colouration (Adetunji & Parr, 1974), and gonad development (Mitchell, 1969). At this stage, adults typically move away from emergent sites also known as the rendezvous (Corbet, 1980) and may return only when sexually matured. The distance of dispersion further away from the rendezvous depends on habitat continuity and the presence of vegetation for shelter (Corbet, 1980). The pre-reproductive stage often lasts between 2 days to a month (Corbet, 1962; Lutz, 1968) for Zygoptera and 2 weeks or less for Anisoptera (Pajunen, 1962; Schmidt, 1964) but is shorter for males (Pajunen, 1962; Schmidt, 1964; Ubukata, 1974) and further prolonged by cold weather (Pajunen, 1962; Ubukata, 1974).

The reproductive stage begins when adults start exhibiting sexual behaviour through copulation. This takes place at the rendezvous and matured adults remain at the rendezvous, only taking short trips at night to roosting sites (Ueda, 1976), during strong winds (Mitchell, 1962) or during aggression from other males (Higashi, 1969). Roosting sites may include dense bushes (Heymer,

1964) and low lying grasses (Hassan, 1976; Parr & Marrion, 1974) and may be less than 200 metres away from the rendezvous (Dumont, 1971; Hassan, 1976; Parr & Marrion, 1974; Ueda, 1976).

Adults, just like larvae, are predators that feed mainly on flying insects (Pritchard, 1964) and are able to detect and capture prey using their compound eyes, similar to larval behaviour. Zygoptera capture prey that are at rest or immobile (Goodyear, 1970; Stortenbeker, 1967) while Anisoptera may capture both flying and resting prey (Edman & Haeger, 1974; Corbet, 1980). Adults of Odonata are described as opportunistic predators hence they rarely diminish prey populations (Corbet, 1980). Adults exhibit a wide variation in colour which is said to arise from polychromatism (colour polymorphism), aging and temperature (Corbet, 1980). Colouration also varies between species and is a key factor for species identification.

In the absence of delayed or arrested development, the maximum life span of Odonata may range between 7 to 9 weeks for Zygoptera and 8 to 10 weeks for Anisoptera (Corbet, 1980), however, some species may live longer extending to 11 or 13 weeks (Degrange, 1971; Degrange & Seassau, 1968). The longevity of adult Odonata may be reduced by the presence of parasites through physical injury (Abro, 1971) or indirect cause of hyperactivity and migration (Dumont & Hinnekint, 1973).

Importance of Odonata in Ecosystems

Odonates, like all other insect groups are important in our ecosystems and play significant roles. Even though the widely known benefits of dragonflies and damselflies are not direct, they provide several benefits to humans, both directly and indirectly. To some authors (eg. May, 2019), the greatest benefit of odonates is intrinsic. The benefits derived from the Odonata ranges from artistic and aesthetic values to their role as bioindicators.

Artistic, aesthetic and cultural Values

The Odonata have been widely used in arts, aesthetics and culture. In Asia for instance, dragonflies and damselflies have inspired several arts and literature as well as poetry. The arts, aesthetics and culture of several other countries have also been inspired by the Odonata. The cultural significance of dragonflies is evident in their use as symbols and emblems by different human societies. To the Indians of Navaho, the Odonata are a symbol of pure water (Simaika and Samways, 2008). To ancient Japanese warriors, the Odonata is known as the invisible insect and was used as a symbol of strength for the warriors (Kritsky and Cherry, 2000). In China and Japan, dragonflies are believed to possess medicinal properties and hence were used by traditional medicine practitioners for healing (Asahina, 1974). In the southwest native America group, dragonflies were valued as signs of water, fertility and abundance and were often used as motifs on pottery (Steinbach & Steinbach, 2002). On the northern plains, the Cheyenne and Dakota believed dragonflies were symbols of good omen and protection against death, and they were often represented on clothing and on dwellings and war shields (Durkin, 1999; Green, 2012).

In terms of recreation, the Odonata can be placed on a similar pedestal as the butterflies. Their presence in and around freshwater systems is appreciated by nature lovers and as such provides a form of recreation for them, and a source of income for conservation strategies that are dedicated to the promotion of recreation. One of such strategies is seen in Japan, where reserves and parks dedicated to Odonata have been well established as a way of promoting conservation awareness (Primack, *et al.*, 2005). Several other parks worldwide also provide dragonfly trails for recreation and the promotion of conservation awareness (Niba & Samways, 2006; Suh & Samways, 2001).

The artistic, cultural and aesthetic values of the Odonata are not only limited to ancient and medieval times however in recent times, they continue to be appreciated. There are currently several organisations globally that are interested in the study of Odonata and continue to promote awareness on the need for the conservation of Odonata. Several field guides have been developed for specific locations and are being used for both academic and non-academic field expeditions and in recent times, areas which are less deficient in terms of knowledge on Odonata populations are being studied and explored (May, 2019). There are still a number of areas, which may be significant and important habitats for the Odonata however they are yet to be fully explored.

Ecological roles performed by Odonata in ecosystems

Dragonflies and damselflies are known to provide significant ecological roles that contribute to supporting services and regulatory services for the sustenance of ecosystems. Generally, supporting services are those that provide indirect benefits to humans and its benefits may be realised over a long period of time (Millennium Ecosystem Assessment, 2005). Supporting services include soil formation, primary production, nutrient and water cycling, among others. The benefits of regulatory services such as air quality, climate, disease and pest regulation may be direct (Millennium Ecosystem Assessment, 2005).

Odonata as predators

Dragonflies are known predators of various insects and other invertebrate groups as well as other Odonata, including the larvae of amphibians, some crustaceans and molluscs, and flatworms (Corbet, 2004). Adult Odonata are also reported to feed predominantly on flies (Diptera). Studies have shown that dragonflies have the potential to be used as biological control agents for mosquito larvae (May, 2019). Studies have shown that dragonflies effectively feed on Diptera and mosquitoes and are effective at capturing individuals (Combes *et al*., 2013). The reduced potential of Odonata as effective biocontrol agents may be due to the fact that both larvae and adult are generalist and they mostly feed on prey that is generally abundant at a given time (May, 2019). Odonata are cannibalistic in nature hence their population density is naturally restricted (May, 2019). Also, the lifecycles of Odonata are generally longer than their prey population hence their response to prey abundance is often slow (May, 2019). Odonata may show variations in prey preference at the species level, feeding n prey belonging to specific taxa (Blois-Heulin, 1985).

Odonates are generally not known to control populations of crop pests however they have been observed to be actively present in paddies and rice fields feeding on various pests as prey however they may not show a significant effect on pest populations (Yasumatsu *et al*., 1975; Corbet, 1999). In some instances, Odonata have been found to feed on beneficial insects. For instance, large aeshnids were observed to hover around bee hives and pick up bees as they move out to feed thereby reducing the number of bee foragers (Wright, 1944). They may also cause harm by consuming wild pollinators. By their role as predators, the Odonata contribute to nutrient cycling between the aquatic environment and the terrestrial environment.

Dragonflies do not require nectar or other plant resources for survival and hence are not known to pollinate any flower or crop of any kind. However, they somewhat play roles in the extent of pollination by their predatory activity. A study conducted by Knight *et al.* (2005) revealed that dragonflies have the potential to reduce the populations of pollinators of insect-pollinated plants near freshwater habitats. Their study revealed that plants that were found near fish containing ponds had a higher number of pollinator visits as compared to plants that were found near ponds without fish. This is because fishes feed on dragonfly larvae and as such reduced the number of adults that emerged. Similar findings were also made by Burkle *et al*. (2012) who demonstrated a negative correlation between pollinators, adult dragonflies, oviposition, plankton species richness, and flower availability after varying the number of flowers surrounding four ponds for eight weeks and observing pollinator visits as well as dragonfly abundance. The findings of Burkle *et al.* (2012) demonstrate how dragonflies, thus Odonata impact both aquatic and terrestrial environments as well as organisms that live within them.

Odonata associations with other organisms

The Odonata, at both the larval and adult stages are known to have associations with other organisms. Associations of odonates with other organisms include predators, commensals, mutualists, pathogens, and parasitism on larvae. Organisms that associate with Odonata as commensals include diatoms, rotifers, molluscs, and other insects. Associations of other organisms sometimes differ with the stage of the Odonata for example water mites are commensal on larvae, but are parasitic on adults (Corbet, 2004). Other commensals with adult dragonflies include pseudo scorpions, biting lice, wasps, milichiid flies, algae, and microorganisms.

Mutualistic relationships also occur between Odonata and other organisms. Examples include the mutualistic relationship between a larva of the damselfly *Mecistogaster ornate* and an alga. The larva serves as a substrate for the alga and positions itself such that there is an increase in the oxygen concentration needed during photosynthesis by the alga. (Willey *et al*., 1970).

Parasites of larval and adult dragonflies include some protozoans, Platyhelminthes, and arthropods. The trematodes are important parasites of Odonata because aside their effects on dragonflies, they infest poultry and humans as well. They are often carried to humans and poultry by dragonflies (Simaika & Samways, 2008). Dragonflies have shown susceptibility to some fungal and insect pathogens including the claviceps and cordyceps (Corbet, 2004) with the water mites being the most prevalent parasites recorded (Smith, 1988). Water mites can be found on dragonflies in almost all freshwater habitat types including lotic or lentic habitats as well as permanent and temporary waters. Comparing associations between dragonflies and damselflies, dragonflies appear to be less parasitized that damselflies (Smith, 1988). Also, generalists are more likely to be infested by mites that specialists and rare species (Grant & Samways, 2007).

Odonata as ecological bioindicators

Bioindicators play important ecological roles in ecosystems due to their characteristics which enable them to be used as tools for assessing ecosystem changes. One key characteristic of bioindicators is that, they should respond easily to changes in the environment such that the change is measurable (Kremen *et al*., 1993). A number of insect groups such as lepidoptera, Hymenoptera and the coleopteran have all been identified as possessing desirable characteristics, mostly depending on their taxonomic and ecological diversity, abundance and ease of capture, ecological fidelity, and current knowledge of group, for bioindication (Brown, 1991). Among these groups is the Odonata, which has been ranked as belonging to the top 20% (Brown, 1991; Sutton & Collins, 1991).

Odonata have been used as indicators of several ecosystem variables including isotope quality (Clark & Samways, 1996), water pollution (Hering *et al*., 2004), water quality (Clark & Samways, 1996; Foote & Rice Hornung, 2005), and change in riparian vegetation (Clausnitzer *et al*., 2009; Dolný *et al*., 2011), in aquatic ecosystems. Based on their use as bioindicators, several indices have been developed for conducting assessments of the health status of aquatic ecosystems using Odonata. The Biological Monitoring Working Party (BMWP) score system was developed to be used as a classification system for river pollution in the UK. This score was based on assessing tolerant and non-tolerant species to urban stressors, and assigning scores to each species (Oertli, 2008). The Dragonfly Biotic Index (DBI) (Simaika & Samways, 2009; Samways & Simaika, 2016) has also been developed for assessing habitat integrity of freshwater ecosystems and for monitoring successes of conservation efforts. Special attention is given to the Dragonfly Biotic Index in this study because as part of the study, a DBI for habitat assessment at the local scale was developed to assess the integrity of freshwater habitats.

The Dragonfly Biotic Index

The Dragonfly Biotic Index (DBI) has proven to be a suitable and excellent index for the use of Odonata for bio-indication (Samways & Simaika, 2016; Uyizeye, 2020; Vorster *et al.*, 2020). The Index can also be used to monitor short and long term changes, as well as the significance of restoration efforts in freshwater habitats (Samways & Simaika, 2016). The index scores species of dragonflies and damselflies based on their distribution across a geographic area, their conservation status according to the International Union for the Conservation of Nature (IUCN) red list (Least concerned, Near threatened, Vulnerable, Critically endangered, Endangered), and their sensitivity to changes in habitat. The DBI was specifically developed based on species present in South Africa (Simaika & Samways, 2009) and was later developed into a Manual for freshwater assessments in South Africa (Samways & Simaika, 2016). Based on the differences in species compositions at the local and national and even continental levels, it is important that DBI's are developed for specific geographic regions to aid in assessment of freshwater habitat integrity (Simaika & Samways, 2009). Consequently, a DBI has been developed specifically for Rwanda (Uyizeye, 2020) and also for Africa as the African Dragonfly Biotic Index (ADBI) (Vorster *et al.*, 2020).

The DBI comprises three sub-indices which must be assessed for each species to determine the overall score for each species as they occur within the designated geographic area. These sub-indices are Distribution Based Score (DBS), Threat Based Score (TBS) and Sensitivity Based Score (SBS) (Table 1).

Table 1: Summary of DBI Sub-indices Scores and Criteria as Developed by Simaika & Samways (2009)

Score	Criteria for Assessment		
	DBS	**TBS**	**SBS**
0	Common and widespread	Least Concerned	Not sensitive
1	Localised across a wide area	Near Threatened	Low sensitivity
2	Endemic to few locations	Vulnerable	Medium sensitivity
3	Endemic to 1 or 2 locations	Critically Endangered	Extreme sensitivity

The DBS described the extent of occurrence of each species within the geographic location of study. Species of Odonata may either be endemic to certain localities or present across larger geographic regions. The TBS describes the threat status of each species based on IUCN red list assessments in order to determine which species require more conservation action. Red List assessments are often conducted either at the national scale, regional, continental or global scale. The status of the species at lower scales are used instead of higher scales however where the Red List status has not been assessed at lower scales (e.g., National), higher scales are used (e.g., Regional or Global). The SBS predicts how sensitive a species is to human disturbance. Some species are able to tolerate human disturbances and habitat modifications and are often widespread in disturbed habitats however some species are sensitive to these changes and as such only inhabit natural or undisturbed habitats. Each sub-index contributes to the overall DBI of the species.

Each Sub-index has a score ranging from 0 – 3, as such the maximum score a species can attain is 9. The overall DBI for each species is determined by the sum of the DBS, TBS and SBS for the species. To assess the DBI of a freshwater habitat, the sum of the DBI of all species present within the habitat is divided by the total number of species within the habitat. The DBI of a habitat therefore ranges from 0 to 9 on a scale of increasing habitat integrity.

Odonata in Ghana

Species abundance and distributions

Studies have been conducted to survey Odonata species as they occur in Ghana however these studies have not fully described all species present in Ghana as well as their distributions and assemblages across the country. Currently, 177 species have been recorded. It is estimated that there are over 50 additional species that are likely to occur in the country, judging from the species present in countries that borders Ghana (Dijkstra, 2007).

The earliest species recorded in Ghana is the *Phyllomacromia Sophia* recorded in the Cape Coast Castle in 1871 (Dijkstra, 2007). Later studies to record species present includes studies by Karsch (1893) (as cited in Dijkstra, 2007) in the Kyabobo National Park. Lacroix (1921) (as cited in Dijkstra, 2007) recorded *Trithemis godiardi*, *Cyanothermis simpsoni* and *Orthertrum microstigma* from Koforidua. Neville (1960) recorded 24 species of Odonata from the Bobiri Forest Reserve while Pinhey (1962), recorded an unspecified number of species from the Prah-Annum Forest Reserve (Dijkstra, 2007). Marshall and Gambles (1977) recorded 46 species from the Mole National Park.

O'Neil and Paulson (2001) recorded the highest number of species (71) compared to prior studies, of which 24 were recorded for the first time from several locations in the country. Other contributions were made by Olsvik (1993) (as cited in Dijkstra, 2007). Dijkstra (2007) recorded 72 species in the Atewa Forest Range Reserve, out of which 8 species were recorded for the first time, and finally drew up a national list of Odonata for Ghana.

Aside studies that led to the discovery of species of Odonata in Ghana, few studies have been conducted to contribute to the diversity and distribution of Odonata across the country. Some studies have also shown the impact of measured climatic and habitat variables on Odonate assemblages in different freshwater and habitat types as well as the impact of changing environment on Odonatan diversities.

Acquah-Lamptey *et al*. (2013b) in their study on "using odonates as markers of the environmental health of water and its related land ecotone" recorded 47 Odonata species within and outside the Atewa Range Forest Reserve, along the stretch of the Densu River which has its head waters from the Atewa Range Forest Reserve. The study was conducted in the Greater Accra and parts of the Eastern Region. They also assessed the effect of stream colour, immediate land use type and vegetation cover on Odonate assemblages. Seidu *et al.* (2017) identified 23 damselfly and 30 dragonfly species in the Atewa range forest reserve along a different anthropogenic disturbance along three rivers which pass through different land use types (agricultural, forest and forest margin). The study identified surface water temperature, canopy cover and channel width as key factors that influenced Odonate assemblages. Seidu *et al.* (2018) in their study to assess Odonate assemblages along an anthropogenic disturbance gradient in Ghana's Eastern Region recorded 51 species of Odonata (20 damselflies and 31 dragonflies) in mining sites, agricultural fields, human settlements, and primary forest habitat. The human settlement recorded the highest Odonata abundance with the highest diversity recorded in mining sites. Key factors that influenced Odonate assemblages were percentage of canopy cover and channel width. Seidu *et al.* (2019) recorded 22 dragonflies and 25 damselflies in various freshwater habitats within and around the Ankasa Conservation Area. Bemah (2019) also recorded 12 damselflies and 13 dragonflies. In a comparative diversity assessment between residential area, garden and farmland to use dragonflies as tools for habitat monitoring, Acquah-Lamptey *et al.* (2013a) identified 26 species. Kyerematen and Gordon (2012) recorded 10 Odonata species as part of an assessment of insect fauna of Rivers Densu, Birim and Ayensu. Kyerematen *et al.* (2014) assessed the insect diversity of the Muni-Pomadze Ramsar Site in Winneba in the central region of Ghana and identified 45 species of dragonflies. Also, Kyerematen *et al.* (2014) assessed the species composition and diversity of insects of the Kogyae Strict Nature Reserve in the Ashanti region of Ghana and identified 20 species.

While a few studies have been conducted, they are not representative of the species distributions of Odonata across the country. Protected areas have often been the focus of Odonata assessments in Ghana with few studies recording Odonata in urban or residential areas. To better understand the diversities and distributions of dragonflies and damselflies in Ghana as well as the factors that structure species assemblages, other areas which have not been surveyed must be assessed.

The Effects of Urbanisation and Anthropogenic Activities on Odonata Assemblages

Factors that affect Odonata in urban areas

It has been shown that urbanisation negatively affects the diversity of dragonflies and damselflies similarly as other insect groups (McKinney, 2008). The factors that affect Odonata in urban ecosystems are several and multi-faceted (Villalobos-Jiménez *et al.*, 2016) and may have varying impact at each stage of odonate life cycle. It is however possible that an effect at one stage may be passed on to other stages through carry-over effects. Example is the transfer of adult maternal effects to larva.

Fragmentation

Fragmentation has been identified as one of the factors that affect Odonata in urban areas. Dragonflies exhibit high dispersal ability and as such, they require a continuous habitat to facilitate dispersal behaviour however, fragmented landscapes limit connectivity of Odonata within urban areas (Chovanec *et al*., 2000; Watts *et al*., 2004; Sato *et al*., 2008). Urban areas were identified to create barriers for some odonate species including *Paracercion calamorum*, *Ischnura senegalensis*, and *I. asiatica* in Japan when the genetic differentiation among populations was analysed (Sato *et al.*, 2008). This finding was buttressed by (Watts *et al.*, 2004), who reported a strong negative effect of urban areas on the dispersal of *Coenagrion mercuriale* using genetic techniques and a mark-release-recapture method. Fragmentation can also have negative effect on habitat selection due to the access limitation to optimal oviposition sites (Villalobos-Jiménez *et al.*, 2016).

Removal and Modification of Vegetation

Vegetation is an important resource for Odonata as shown in a number of studies in France (Jeanmougin *et al*., 2014), Germany (Goertzen & Suhling, 2013), Austria (Chovanec *et al*., 2000) and South Africa (Pryke & Samways, 2009; Samways & Steytler, 1996), where a positive correlation was observed between richness and evenness of Odonata, and increased vegetation cover and diversity of plants. Vegetation is important because it serves as a key signal for habitat selection and it has influence on odonate behaviours including foraging, basking, sheltering and roosting (Buchwald, 1992). As such, a change in the vegetation around urban freshwater habitats may affect the behaviour of adult Odonata as well as other stages of the life cycle. Endophytic Odonata utilise vegetation as oviposition substrates and their larva, after emergence, utilise submerged plants as perching sites, for camouflage, and also for hunting prey (Buchwald, 1992). Some species also rely on specific plants and may be affected by their removal for example *Aeshna viridis* only oviposits on *Stratiotes aloides* (Dijkstra, 2006).

Not all species are sensitive to vegetation loss or modification hence not all species may be affected by the removal or modification of vegetation. Goertzen and Suhling (2013) studied the diversity of Odonata in ponds along an urban rural gradient. Their study revealed that though vegetation is a key resource for Odonata, it was not the only factor responsible for driving variations in alpha diversity. Mere trampling of vegetation also showed a significant negative effect on diversity. This is similar to other studies which have suggested that the percentage cover of aquatic plants such as submerged macrophytes also affects diversity of Odonata (Jeanmougin *et al*., 2014). Also, indigenous vegetation play key roles in conserving rare and sensitive species as asserted by Samways and Steytler (1996), who reported that leaving about 20 m of indigenous riparian vegetation between a stream and commercial plantation was effective for the presence of *Chlorolestes tessellatus* in South Africa.

Pollution

Pollution is common in urban environments due to the high production of domestic, commercial and industrial waste. Waste materials are often discarded through gutters and streams and end up in larger aquatic systems. Studies have reported a negative effect on urban pollution on the diversities of adult Odonata (Solimini *et al*., 1997; Henriques-de-Oliveira *et al*., 2007). Urban pollution may however favour the abundance of certain species or groups due to the variations in the tolerance levels of different species and groups of Odonata. An increase in abundance and dominance of Libellulidae and a decrease in the abundance of Gomphidae was observed in urban polluted water bodies (Ferreras-Romero *et al*., 2009). It is of importance to mention that sensitivity and tolerance of pollutants is highly dependent on the species rather than the family or other taxon levels hence species must be used as indicators (Villalobos-Jiménez *et al.*, 2016).

Pollution of urban aquatic systems may occur as a result of the introduction of several contaminants including organic and inorganic fertilisers or pesticides, heavy metals, as well as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) (Paul & Meyer, 2001). These contaminants may have effects on larval Odonata due to their potential to reduce dissolved oxygen content of freshwater habitat. A high amount of organic matter in freshwater habitats often lead to eutrophication with associated algal and bacteria blooms (Forman, 2008). In addition, high levels of organic and inorganic contaminants may be toxic for some species leading to an increase in larval morality as shown for pesticide toxicity (Chang *et al*., 2007). Species may however be affected differently by the type of pesticide and to what extent the species is exposed. *Coenagrion puella* showed an increase in the rate of development after it was subjected three different pesticide treatments (Campero *et al*., 2007).

In *Ischnura elegans* larvae, pesticide exposure led to a decrease in immune function which resulted in subsequent deterioration of immune function in the emerged adults after they were subjected to heat stress (Janssens *et al*., 2014). For some urban populations of *C. puella* larvae, an increase in activity was observed after exposure to chlorpyrifos at 20° and 24°C, and as temperature was increased, their food intake reduced which was the opposite for rural populations (Tüzün *et al*., 2015). These results suggest that urban larvae populations are locally adapted to higher contaminant levels (Tüzün *et al*., 2015).

Contaminants, mainly PCBs and heavy metals, also have the potential of accumulating in the tissues of Odonata. 209 different types of PCBs were found to have accumulated in chironomids and dragonflies at high concentrations in urban freshwater habitats in Beijing (Yu *et al*., 2013). Similarly, other organic pollutants including polybrominated diphenyl ethers (PBDEs) and hexachlorobenzene (HCB) were also found in the larvae of *I. elegans* in ponds across Flanders, Belgium (Van Praet *et al*., 2012). Heavy metals, which are often introduced into freshwater habitats by road run-off and sewage have also been found to accumulate in the exoskeleton of Odonata larvae (Meyer *et al*., 1986). Although lead and copper can cause deformities in other insects, e.g. *Chironomus mentum* (De Bisthoven *et al*., 1998), *Aeshna juncea* showed tolerance of high concentrations of manganese and nickel, while *Platycnemis pennipes* showed a sensitivity to cadmium, boron, and iron (Girgin *et al*., 2010), providing evidence of their use as suitable candidates for biomonitoring programmes.

Change in behaviour

Urban environments have the potential to change the behaviour of Odonata. One of such means in the creation of ecological traps, which refers to “situations in which unsuitable sites unable to sustain a population are preferred over the suitable sites or the unsuitable habitats mimic the cues that species use for selecting ideal habitats, leading species to choose unsuitable habitats over the optimal sites for roosting, feeding, and mostly reproducing” (Donovan & Thompson, 2001; Schlaepfer *et al*., 2006). Changes in the environment are the main causes of ecological traps (Schlaepfer *et al*., 2002). Human constructions and changes often include the creation of shiny surfaces that reflect light. The oviposition behaviour of Odonata is known to be influenced by the degree of polarisation of light from water surfaces. These shiny surfaces present in urban areas sometimes reflect polarised light to extents that are sometimes greater than water and are selected by Odonata as oviposition sites (Villalobos-Jiménez *et al*., 2016). A common observation is the presence of some species of dragonflies in car parks due to the reflecting surfaces of car wind screens and mirrors. In Brazil for instance, *Pantala flavescens* was present in parking areas and oviposited on cars (Van De Koken *et al*., 2007). Acquah-Lamptey *et al*. (2013b) also observed the presence of *Bradinopyga strachani* flying over parked cars in a study on the campus of the University of Ghana.

Aside cars, other shiny surfaces have been observed to alter the oviposition behaviour of Odonata. Black plastic foils (Wildermuth, 1998), crude oil ponds (Horváth *et al*., 1998) and grave stones (Horvath *et al*., 2007) have all been identified as ecological traps for Odonata. According to Kokko and Sutherland, (2001), this behaviour could lead to an allele effect in species with low population densities. It is very possible that in species with higher densities, individuals would rather compete for unsuitable habitats as oviposition sites while weaker individuals that may have a weaker fitness would rather settle for the suitable habitats which may be less preferred. Ecological traps therefore have the potential to decrease the population density of species and serve as a driving factor towards extinction in species (Kokko & Sutherland, 2001; Schlaepfer *et al*., 2002).

Importance of urban areas for the conservation of Odonata

Studies conducted on Odonata in urban areas show that the impact of urbanisation on Odonata is not entirely negative however the negative effects arise from the intensive use of urban landscapes due to anthropogenic activities. Some urban areas that were identified to have diverse vegetation with little activities that lead to pollution had high Odonata diversity as compared to urban areas with less vegetation and high levels of pollution (Colding *et al*., 2009; Goertzen & Suhling, 2013). In the Netherlands, urban drainage systems were richer in macroinvertebrate diversity as compared to rural drainage systems because the urban drainage systems were less polluted and had a diverse vegetation (Vermonden *et al*., 2009). An increase in the diversity of Odonata was also observed in Austria in the Danube River floodplain after vegetation was increased due to an implementation of a water enhancement program (Chovanec *et al.*, 2000; Chovanec *et al*., 2002).

In South Africa, botanical gardens which contained diverse plant communities recorded the highest richness and abundance of Odonata when compared with natural and recovering forests, and with alien pine plantations (Pryke & Samways, 2009), which proves that botanical gardens are significant refuge grounds for invertebrates. Similar observations were made when the diversity of Odonatan in parks in South Africa were compared to alien planation forests (Samways & Steytler, 1996). These findings seem to suggest that the kind of vegetation in freshwater habitat have the potential to influence the diversity and abundance of dragonflies and damselflies.

In urban ecosystems, a wide variety of aquatic habitats are present which include ponds of different types, streams, and temporary pools of water (Hassall, 2014). This variety provides different ecological and environmental conditions that may be required by a wide range of species thereby promoting higher diversities of Odonata (Goertzen & Suhling, 2013). Even though generalists are abundant in cities, there are some specialists that have been found in urban habitats. For example, *Coenagrion ornatum*, a threatened damselfly, was recorded in drainage systems (Harabiš & Dolný, 2015). Golf courses in Sweden also serve as a refuge for some endangered species such as *Leucorrhinia pectoralis* (Colding *et al.*, 2009). *Ischnura gemina* is endemic to the San Francisco Bay area, USA, which is highly urbanised.

Even though some specialists have been found in urban areas, their populations continue to decline as observed for *I. gemina* (Hannon & Hafernik, 2007). It is therefore important that conditions required for such specialists to survive in urban areas are met. By so doing, the requirements for other odonates as well as other invertebrates would be met (Bried *et al*., 2007). This would help save time and effort in developing cities that are biodiverse and sustainable.

Survival and adaptation of Odonata in urban areas

Despite the negative impacts of urban areas, some species of Odonatan have adapted to the various stressors that are present. This has been achieved by changes in life history traits and life cycle to accommodate for the stressors in urban areas. According to (Solimini *et al*., 1997), *Erythromma lindenii* and *Ischnura elegans* are able to withstand organic pollution by having a longer reproductive period, an absence of diapause and ability to tolerate low oxygen levels. *Sympetrum striolatum* was also observed to synchronise its life cycle with the periods for using swimming pools. In the autumn, the species was observed to lay eggs in the pools while the larvae hatches in mid-winter with the emergence of adults occurring before pools are drained and cleaned (Matsura *et al*., 1995, 1998).

Environmental Conservation Obligations in Ghana

Globally, the need for the conservation and protection of natural areas has been the concern of conservationists in recent times. As a result, a number of conventions and laws have been enacted as guidelines for protecting several aspects of the environment. These conventions are aimed at protecting natural resources from further destruction and restoring natural resources that have already been the subject of destructive activities. The convention on Biological Diversity, which came into force in 1993, is one of the key legal frameworks for the sustainable use of natural resources. It has been ratified by 196 countries of which Ghana is a party. Given that Ghana's environment is threatened by factors including land-use conversions, habitat degradation, pollution, over-exploitation, invasive alien species, climate change, predation, wildfires and poaching, as well as over-harvesting of genetic resources and misapplication of chemicals (Botchway & Hlovor, 2019), it is important that the strategies provided by the CBD are implemented towards the protection of the environment and associated biodiversity. Ghana is obligated by the convention to adopt and implement global frameworks and develop national biodiversity strategies and action plans to meet periodic conservation objectives provided by the convention (Convention on Biological Diversity, 2010). Currently, a Global Biodiversity Framework has been proposed for conservation actions in the post-2020 era to achieve a vision 2050 of "Living in Harmony with Nature" (Convention on Biological Diversity, 2020).

The Ramsar Convention (1973) is also one of the global conventions of which Ghana is a signatory to. The Convention proposes strategies for the protection of wetlands, including coral reefs and estuaries (Van Rees *et al*., 2021). The Convention however does not cover the protection of other freshwater habitats including streams, rivers and ponds. The protection of these habitats has been lumped together with strategies for conserving terrestrial habitats and the framework developed by the CBD provides these strategies for freshwater conservation (Van Rees *et al*., 2021). The CBD Strategic Plan for Biodiversity 2011–2020 included 20 Aichi Biodiversity Targets. Among the most relevant to freshwater are Target 11, the conservation of terrestrial and inland waters and marine areas, Target 5, halving the rate of habitat loss, Target 12, no extinctions, Target 8, the reduction of pollution pressures, and Target 9, the prevention, eradication and control of IAS (Van Rees *et al*., 2021). Ghana as a party is obligated to achieve these targets.

CHAPTER THREE

MATERIALS AND METHODS

This chapter describes where the study was conducted, how the study was conducted and how the data collected were analysed to answer the questions that the study sought to address. The chapter details the protocols used to conduct Odonata surveys and how the environmental variables were measured as well as the various statistical tools that were used for the analysis of data.

Study Area

The study was conducted in 16 freshwater habitats in different locations within the Cape Coast Metropolis, in the Central Region of Ghana (Figure 2). The Cape Coast Metropolis occupies an area of approximately 126 km^2 and has an estimated human population of 169,894 as at 2010. The area presents a unique coastal ecosystem, with the ocean having little to moderate effect on the local climate (Deikumah & Kudom, 2010). Due to the area being a coastal area, it contains brackish water systems in addition to freshwater habitats. Climatic variables include a double peak rainfall level of 750 mm and 1000 mm with major rains occurring between May and July, and minor rains between November and January. The area also experiences an average monthly relative humidity varying between 85% and 99%.

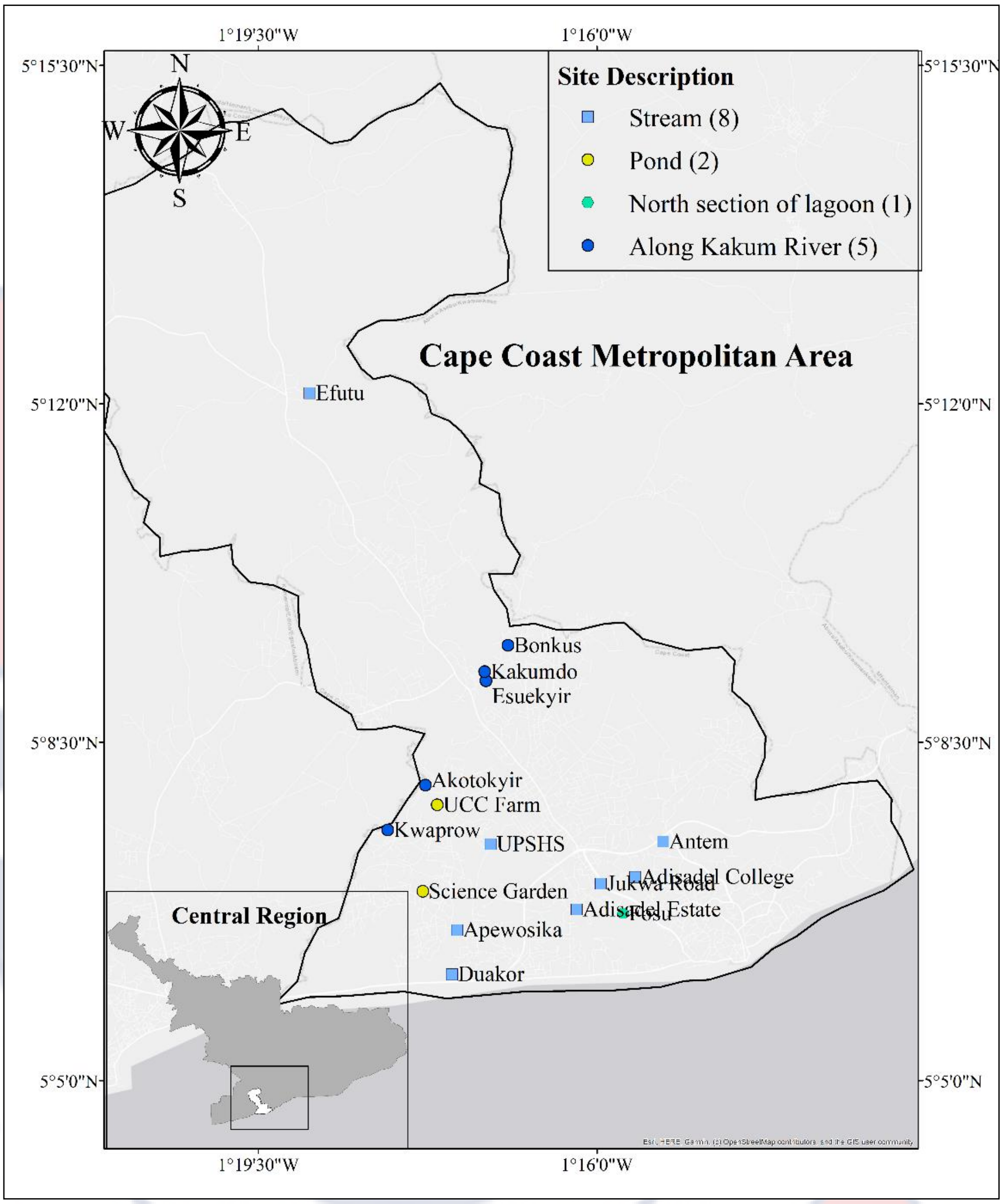

Figure 2: Map of the Cape Coast Metropolitan Area showing the selected habitats used for the study.

The freshwater network within the area comprises different streams that flows between hills and through various communities. The area is characterised by minor stream networks which flow into larger water bodies or into wetlands. The Kakum River is the major freshwater system in the Metropolis. The Kakum stream obtains its source from the Kakum National Park, which lies north of the Metropolis, flowing through several forest areas and communities to join the sea at Iture. The area is characterised by natural and artificial ponds as well as several temporal pools of water, often visible in the rainy seasons.

The area is also characterised by remnant forests that surrounds several communities through which some streams pass, with shrubs and grasslands forming a significant part of the vegetation (Deikumah & Kudom, 2010). Freshwater habitats are characterised by a gradient of different levels of disturbance ranging from direct discharge of domestic effluents to partial and total removal of riparian vegetation, with few streams lying in less disturbed areas. Levels of urbanisation around streams also vary from areas of heavily built areas to areas of fewer buildings and higher vegetation. The area therefore presents an opportunity for biodiversity assessments and comparisons across a gradient of urbanisation, human disturbance and environmental impacts.

Site selection

Preliminary survey was conducted to identify freshwater systems within the study area. Freshwater bodies including ponds and streams were considered. Multiple sites were selected along the streams. Small streams and ponds were considered as single sites. The GPS coordinates of all potential sites were recorded and from them, the final selected sites (Table 2) were at least 500 m apart from each other, based on reports of the extent of habitat requirement of adult Odonata around their native habitats (Purse *et al*., 2003; Dolny *et al*., 2014; Deacon & Samways, 2021) in order to avoid multiple counts of individuals.

Table 2: Names, GPS Coordinates and Habitat Type of Study Sites.

Site	Location	GPS Coordinate	Habitat Type
1	Adisadel Estate	5.112852, -1.270134	Stream
2	Adisadel College	5.1184542, -1.260056	Stream
3	Akotokyir	5.134275, -1.296217	A. Kakum River
4	Antem	5.1245568, -1.2552608	Stream
5	Apewosika	5.1093176, -1.2907532	Stream
6	Bonkus	5.158371, -1.28198	A. Kakum River
7	Duakor	5.1016652, -1.2916388	Stream
8	Efutu	5.2018574, -1.3161675	Stream
9	Esuekyir	5.1522532, -1.2858034	A. Kakum River
10	Fosu Lagoon	5.1121538, -1.2621167	Lagoon
11	Jukwa Road	5.1173155, -1.2659988	Stream
12	Kakumdo	5.153818, -1.286019	A. Kakum River
13	Kwaprow	5.1265205, -1.3027241	A. Kakum River
14	Science Garden	5.1159472, -1.2966833	Pond
15	UCC Farm	5.1308729, -1.2941766	Pond
16	UPSHS	5.1240933, -1.2849778	Stream

Collection and Documentation of Odonata in Freshwater Habitats

Sampling protocol

A reach of 150 m was demarcated for each site and subdivided into 3 sections of 40 m each. Each section was demarcated at least 15 m apart from adjacent sections. At each section of a site, Odonata within 5 m perpendicular to the site inland, and 5 m over the water surface were collected using sweep nets as described by Costa Bastos *et al.* (2021) with modifications to the distance demarcations of the sections and intervals between sections (Figure 3). At each section, collections were conducted for 20 minutes.

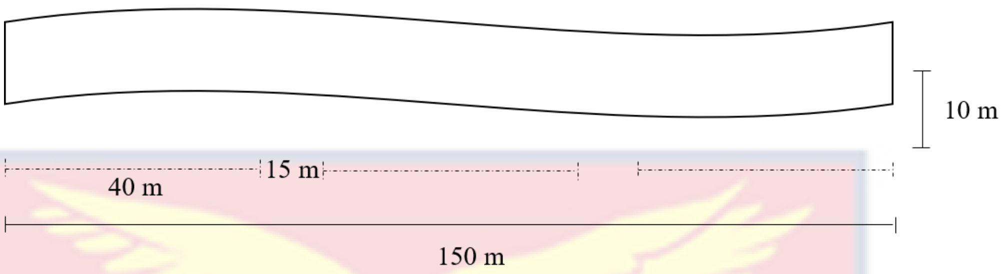

Figure 3: Pictorial representation of experimental design adopted for sampling adult dragonflies and damselflies.

Collected specimens were identified in-situ immediately after collection using field guides by Dijkstra and Clausnitzer (2014) and released back into the wild. Where identification of specimens was difficult in-situ, specimens were transported to the Entomology Museum, UCC in paper envelopes for further observation and identification using the African Dragonfly and Damselfly Online (ADDO) database (Kipping *et al*., 2009) as reference. Photographs of specimens were also taken with a camera (Canon G7, Canon Inc., Ōta, Tokyo, Japan) to assist in identification. The support of other taxonomists and odonatologists was also sought for the identification of species.

In areas where collections were impossible, Odonata were observed by the use of a pair of binoculars (Hawke Nature-Trek 8 x 42) and identified using field guides. Voucher specimens of species identified were deposited in the museum of the Department of Conservation Biology and Entomology, UCC for reference. Survey of Odonata were conducted between 09:00 hrs and 16:00 hrs on sunny days and less windy days. Each site was visited four times between January and June, 2022.

Assessing the effects of human activities on freshwater habitats

A habitat integrity index was generated for each site to evaluate the environmental integrity of the freshwater habitats through visual assessments (Costa Bastos *et al.*, 2021). The habitat integrity index quantifies the structural characteristics of the surrounding banks of water bodies. It gives an estimate of the condition of the freshwater habitats that might have been caused by human disturbance. Eleven parameters were visually assessed using a modified Habitat Integrity Index (HII) by Monteiro-Júnior *et al.* (2014) based on known effects of urbanisation on Odonata (Clark & Samways, 1996; McKinney, 2002; Couceiro *et al*., 2007).

Aspects of the HII (Table 3) as developed by Monteiro-Junior *et al.* (2014) were modified for use in this study. All variables were scored between 0 – 3 as such the conditions for each variable whose scores exceeded 3 according to the criteria set by Monteiro-Junior *et al.* (2014) were revised. For example, Monteiro-Junior *et al.* (2014) scored the width of riparian forests from 0 – 5 to account for the habitat characteristics of urban sites and sites located within the Amazonian Forest. Since the sites assessed in this study fell within an urban area, the variable was modified as width of riparian vegetation to account for the vegetation along the site irrespective of whether it was a forest, grassland, or shrub (Table 3). The types of vegetation were however captured under the condition of the riparian vegetation. Furthermore, channel structure, which measures the width to depth ratio was omitted from this study since the study did not only focus on streams. A variable which assessed the presence or absence of cropland along the water body was introduced in this study because farming activities may also contribute to the level of disturbance on the water body. Other modifications included the assessment of riparian vegetation on both sides of the water body. The HII did not account for the differences in vegetation on both sides of the water body and hence was modified.

Table 3: Habitat Characteristics, Conditions and Scores Used for Habitat Integrity Evaluation

	Characteristic	Condition	Score
1	Access to freshwater habitat	Paved road	0
		Unpaved road	1
		Track road	2
		Path way	3
2	Width of the riparian vegetation	Absence of riparian vegetation	0
		Riparian vegetation, 1 – 5 m wide	1
		Riparian vegetation, 5 – 30 m wide	2
		Riparian vegetation >30 m wide	3
3	Preservation of the riparian vegetation	Vegetation on both sides of bank cleared	0
		Vegetation on either or both sides intact but with frequent gaps	1
		Vegetation on either or both sides intact but gaps at intervals of 25 – 50 m	2
		Vegetation on both sides intact	3

Table 3: cont.

4	Condition of the riparian vegetation within 10 m of the stream	Grass with some shrubs.	0
		Grass mixed with some pioneer trees and shrubs.	1
		Regenerating habitat or pioneer species mixed with mature trees.	2
		More than 90% of the vegetation constituted by native or non-pioneer trees.	3
5	Water retention mechanisms	Retention by five or more of the following: plastic, metal, glass, rubber, building materials, organic matter.	0
		Retention by three or more of the following: plastic, metal, glass, rubber, building materials, organic matter.	1
		Retention by one or more of the following: plastic, metal, glass, rubber, building materials, organic matter.	2
		Retention by leaves and trunks with no urban refuse.	3
6	Canopy cover	Open – 0% to 20%.	0
		Partly open – 20% to 50%	1
		Intermediate – 50% to 70%.	2
		Closed – 70% to 100%	3

Table 3: cont.

7	Presence/Absence of Cropland/Farmland	Presence of farmland on either side of bank	0
		Presence of farmland within 50 m away from bank	1
		Presence of farmland >50 m away from bank	2
		Absence of farmland	3
8	Absence of human occupation	Urban or industrial development on the stream bank	0
		Urban or industrial development at a distance of less than 15 m from the edge of the stream	1
		Urban or industrial development at a distance of less than 25 m from the edge of the stream	2
		Urban or industrial development at a distance of more than 50 m from the edge of the stream	3

Table 3: cont.

9	Absence of domestic or industrial waste	Domestic or industrial effluents discharged directly into the stream	0
		Urban development without adequate public sanitation, with waste being discharged near or into the stream	1
		Urban or industrial development connected to public sanitation network and treatment stations	2
		No buildings or effluent discharge	3
10	Building density (within 100 m)	More than 100 buildings.	0
		Between 51 and 100 buildings.	1
		Between 11 and 50 buildings.	2
		< 10 buildings	3
11	Dumping sites	Presence of active dumping sites inside or near (<20 m) water body	0
		Presence of inactive dumping sites inside or near (<20 m) water body	1
		Presence of dumping sites (active or inactive) >20 m further away from water body.	2
		No evidence of dumping sites	3

Characteristics of each habitat were assessed by evaluating the conditions and a score assigned to each condition of a characteristic. Overall Habitat Integrity Index (HII) values range from 0 to 1, in order of decreasing habitat disturbance. HII values were determined for each site using the formula: Habitat Integrity Index (HII) = $\frac{\Sigma pi}{n}$, where pi (overall score for each characteristic) = $\frac{ax}{am}$; ax = the score for each characteristic, am = maximum possible score for each characteristic, n = number of characteristics measured. Based on HII values, habitats were categorised into least disturbed ($0.7 > x <$ 1.0), moderately disturbed ($0.4 > x < 0.7$) and highly disturbed ($0 > x < 0.4$) based on habitat categorisation by Monteiro-Junior *et al* (2014) (i.e., Preserved habitats: 0.7 – 1.0; Intermediate habitats, $04 > x < 0.7$, degraded habitats, <0.4).

Measuring Environmental Variables

Environmental variables that are likely to impact Odonate assemblages within the area were assessed and recorded. The following parameters were therefore measured at each study site; Water temperature, pH, atmospheric temperature, humidity, wind speed, light intensity. The parameters were recorded on each visit (four replicates) and the means were determined. To measure pH, samples of water were collected on two visits and brought to the Laboratory for measurement. The pH was measured using a pH meter (JENWAY 3510, Essex, England). Temperature, humidity, and wind speed were recorded using a Weather Station (WS-2000, Ambient Weather, Arizona, USA). Light Intensity was also recorded using a light meter (URCERI MT-912, ATP Electronics, Staffordshire, UK).

Developing a local Based Dragonfly Biotic Index for habitat assessment

A local based dragonfly biotic index was developed to assess the integrity of freshwater habitats in the Cape Coast Metropolis based on the Dragonfly Biotic Index developed for South Africa (Simaika & Samways, 2009; Samways & Simaika, 2016). The Dragonfly Biotic Index comprises of three sub-indices; Distribution Based Score (DBS), Threat Based Score (TBS) and Sensitivity Based Score (TBS) that are assessed for each species based on which the integrity of a site can then be assessed. The DBI of South Africa was developed as a national tool for assessing the integrity of freshwater habitats in the country. As such, DBS and SBS were based on the extent of occurrence of species across the country. However, this study was conducted in one Metropolis therefore the DBI of South Africa cannot be applied as a whole in this context. Refer to Chapter Two (page 25) in this document for further information on the Dragonfly Biotic Index. Based on this, slight modifications have been made for the DBS and SBS to fit the context of a local scale assessment (Table 4). The TBS was not modified because it is based on the IUCN redlist category of species for Global, Continental or Regional red list assessments.

Table 4: Criteria for Local Based Dragonfly Biotic Assessment Developed for the Cape Coast Metropolis

Score	Criteria
	Distribution Based Score (Based on the extent of occurrence of species within surveyed habitats)
0	Very common and widespread (found in at least 80% of habitats)
1	Common but not present in all sites (at least 50%)
2	Present in some sites but not common (at least 30%)
3	Restricted to few or specific sites (less than 30%)
	Threat Based Score (Based on IUCN Red list category for each specie; Global, Continental or Regional Assessments)
0	Least Concerned
1	Near Threatened
2	Vulnerable
3	Endangered, Critically Endangered, New species
	Sensitivity Based Score (Based on tolerance to disturbance; disturbance is defined here as signs of the presence of human activities on bank of water, artificial habitat or presence of alien plants)
0	Not sensitive: 2/3 of habitats within which the specie is found are disturbed
1	Low sensitivity: 1/3 of habitats within which the specie is found are disturbed
2	Medium sensitivity: Less than 1/3 of habitats are disturbed
3	High sensitivity: Present in undisturbed habitats, natural or intact habitats

The DBI of each species were calculated as a sum of the scores assigned for DBS, TBS and SBS therefore the maximum DBI a species can attain is 9. The overall DBI for each site was also calculated by dividing the sum of individual DBI of species present at a site by the number of species recorded at the site. The maximum DBI a site can attain is 9. Overall DBI (each site) = $\frac{\sum DBI1\ DBI2+DBI3+\ldots+DBIn}{N}$ where, N = number of species recorded at the site, 1, 2, 3…n, represent the individual species.

Data Analysis

All analyses were performed in R program (R-Development-Core-Team, 2016).

Diversity estimates

Shannon Wiener diversity index (H'), Pielou's evenness and Species Richness were computed to determine the diversities, evenness and richness for each study site/habitat and Habitat condition. Shannon diversity was calculated as: $H' = \sum pi \log(pi)$, where pi is the proportion of each species with respect to the total number of species. Pielous' evenness was calculated as the Shannon diversity index divided by the natural log of the number of species; J = H'/ln(S). Richness was evaluated as the number of species recorded per site/site condition. Diversity and Richness were determined using the "diversity" and "specnumber" functions in "vegan" package (Oksanen *et al.*, 2022). Chao, jacknife and bootstrap diversity estimators were used to estimate the potential number of species that are present with the study area using the "specpool" function in vegan (Oksanen *et al.*, 2022). Species abundance was determined as the overall number of individuals per species that were recorded during the entire period of the study. Normality of species abundance data, as well as diversity and richness were tested using Shapiro Wilks normality test. Transformations (log, log + 1, sqrt, cube root) were applied to abundance, diversity and richness data.

Species abundance data was not normally distributed (before and after transformation) therefore the non-parametric Kruskal-Wallis test was used to compare the differences in species abundance between sites and site categories. Kruskal-Wallis test was also conducted to test for the differences between abundance of each species. Tests for differences was also conducted for abundance, diversity and richness between the categories of study sites based on their habitat integrity. Where differences were significant, Post-Hoc test was conducted using Dunns post-hoc with Bonferroni correction in “FSA” package (Ogle *et al*., 2022) to determine pairwise differences between the groups.

Assessing Impacts of Environmental and Habitat Characteristics on Odonate assemblages

Effects on species abundance, diversity and richness.

The effect of environmental parameters and habitat characteristics on species abundance, diversity and richness were evaluated using mixed effect models. Prior to the building of models, a correlation matrix was generated using the “Hmisc” package (Harrell Jr, 2022) to compare correlation between the measured variables to avoid multi-collinearity. Variables that recorded a Pearson correlation coefficient of > ±0.5 were removed and not included in the analysis. Where a single variable correlated with more than one or more variable, only one variable was removed and the rest were kept provided they were also not strongly correlated with other variables.

Generalised linear mixed effect models were used to test for the effect of each of the environmental and habitat characteristic parameters on species abundance using the “lme4” package, with site and visit as random factors, and initially specifying the Poisson family prior to test for overdispersion. The models were tested for overdispersion using the “testDispersion” function in “DHARMa” package (Hartig, 2022). Models were overdispersed hence quassipoisson family or negative binomial family were the most appropriate families to correct for overdispersion. The glmer function however does not allow for quassipoisson families hence negative binomial family in the MASS package was specified for all models, following guidelines by Bates *et al*., (2015). All parameters of the model were scaled using the “scale ()” function to address the differences in the units of measurement of the variables.

Linear mixed effect model was used to test for the effect of environmental parameters and habitat characteristics on the diversity and richness of Odonata species with site and visit as random factors. Predictors in the model were selected using stepwise selection to determine the best model, defined as the model with the highest AIC, using the stepcAIC function in cAIC4 package (Säfken *et al*., 2021). Chisquare wald test was used to test for the significance of the variables in the model.

Effects on species composition

To evaluate how species compositions between sites differ along the site condition gradient, a multivariate approach was adopted to determine how the measured environmental variables and habitat characteristics contribute to the structuring of Odonate assemblages. Non-Metric Multidimensional scaling (nMDS) with Bray Curtis dissimilarity distance in the “vegan” package (Oksanen *et al*., 2022) was used to visualise similarities and differences in species compositions across the disturbance gradient. PERMANOVA was conducted using the “adonis” function in “vegan” to test for the differences in species compositions across the sites. Redundancy Analysis (RDA) was conducted to determine the influence of each of the variables on the species composition across the disturbance gradient. Analysis of variance (ANOVA) of RDA results was conducted to determine the p-values of each parameter.

For analysis, data from all visits made to each site were combined. Analysis was conducted separately for dragonflies (Anisoptera) and damselflies (Zygoptera) due to their differences in habitat requirements (May, 1976).

CHAPTER FOUR

RESULTS

This chapter presents the findings of the study based on the objectives that were set. The chapter begins by presenting the record of dragonflies and damselflies from the Cape Coast Metropolis. The abundance, diversities and richness of the study sites are also presented after which results on the impact of habitat conditions on Odonate assemblages are also presented. The last section of the results focused on how to apply Odonata to assess the integrity of freshwater habitats. The outcomes of analysis of the results performed are also presented. Results are presented using tables and figures where necessary.

Documentation of Odonata within the Cape Coast Metropolis

This study presents the first record of species of dragonflies and damselflies in the Cape Coast Metropolis. A total of 26 species were recorded during the surveys. This comprises 8 species of damselflies (Zygoptera) (Table 5) and 18 species of dragonflies (Anisoptera) (Table 6).

Table 5: Species of Damselflies Recorded in the Cape Coast Metropolis.

Family	Species	RA (%)
Calopterygidae	*Phaon Camerunensis* Sjöstedt, 1900*	4.64
Chlorocyphidae	*Chlorocypha curta* (Hagen in Selys, 1853)	0.66
Coenagrionidae	*Ceriagrion glabrum* (Burmeister, 1839)	65.5
	Ischnura senegalensis Rambur, 1842	20.6
	Ceragrion sp Selys 1876	6.19
	Agriocnemis zerafica LeRoy, 1915	1.55
Platycnemididae	*Allocnemis ellongata* (Hagen in Selys, 1863) *	0.66
	Allocnemis sp Selys, 1863	0.22

RA = Relative abundance; Asterisk (*) indicate habitat specialists according to descriptions by Dijkstra and Clausnitzer (2014).

Table 6: Species of Dragonflies Recorded in the Cape Coast Metropolis.

Family	Species	RA (%)
Aeshnidae	*Anax tritis* Hagen, 1867	0.5
Gomphidae	*Paragomphus serrulatus* (Baumann, 1898) *	0.2
Libellulidae	*Crocothemis erythrae* (Brullé, 1832)	11.6
	Bradinopyga strachani (Kirby, 1900)	3.6
	Palpopleura lucia (Drury, 1773)	10.6
	Brachythemis impartita (Karsch, 1890)	6.7
	Brachythemis leucostica (Burmeister, 1839)	2.5
	Orthetrum austeni (Kirby, 1900) *	3.6
	Trithemis arteriosa (Burmeister, 1839)	36.0
	Diplacodes lefebvrii (Rambur, 1842)	0.2
	Acisoma inflatum Selys, 1882	4.3
	Orthetrum chrysostigma (Burmeister, 1839)	13.6
	Aethiothemis spp Martin, 1908	1.4
	Nesciothemis pujoli Pinhey, 1971	3.0
	Palpopleura portia (Drury, 1773)	1.0
	Pantala flavescens (Fabricus, 1798)	0.6
	Brachythemis lacustris (Kirby, 1889)	0.4
	Trithemis sp Brauer, 1868	0.1

RA = Relative Abundance; Asterisk (*) indicate habitat specialists according to descriptions by Dijkstra and Clausnitzer (2014).

Four (4) species of damselflies were recorded belonging to the family Coenagrionidae while 2 species belonging to the family Plactynemididae were also recorded. Odonata families, Calopterygidae and Chlorocyphidae recorded only 1 species each. Dragonfly species recorded belong to the families Libellulidae, Gomphidae and Aeshnidae. Family Libellulidae recorded 14 species with Gomphidae and Aeshnidae recorded only 1 species each in this study. At the species level, the most dominant dragonfly species recorded was *Trithemis arteriosa* and was recorded in 14 out of the 16 sites followed by

Orthetrum chrysostigma which was recorded in 12 sites. *Ceriagrion glabrum*, which was the most dominant damselfly was recorded in 14 out of the 16 sites followed by *Ischnura senegalensis*, which was also recorded in 10 sites. The species of four genera identified could not be confirmed, however 2 of these genera recorded a single individual.

In terms of species occurrence, the damselfly, *Allocnemis ellongata* was recorded in only 2 sites in stream habitats while the damselfly, *Phaon camerunensis* was recorded in 4 sites. Interestingly, these sites were all river habitats. *Chlorocypha curta* was also recorded in the Akotokyir river. For dragonflies, *Brachythemis leucostica* was unique to Fosu lagoon habitat, *Palpopleura portia* was recorded only in UCC Farm Pond, *Paragomphus serrulatus* was also recorded only in the Akotokyir river, while *Trithemis sp* was recorded in Adisadel College stream.

The differences between the relative abundance of species was significant for damselflies (Kruskal-Wallis Test, H (7) = 15.236, *p-value* = 0.033) and dragonflies (H (17) = 59.511, *p-value* <0.05). The differences between individual species abundances were not significant for pairwise comparison after post-hoc test for damselfly abundance. A significant difference was observed between the abundance of *Acisoma inflatum* and *Trithemis arteriosa* (adjusted *p-value* < 0.05). Species accumulation curves show that curves for majority of the study sites are approaching asymptote indicating that the number of samples and the species recorded in this study are adequate (Figure 4).

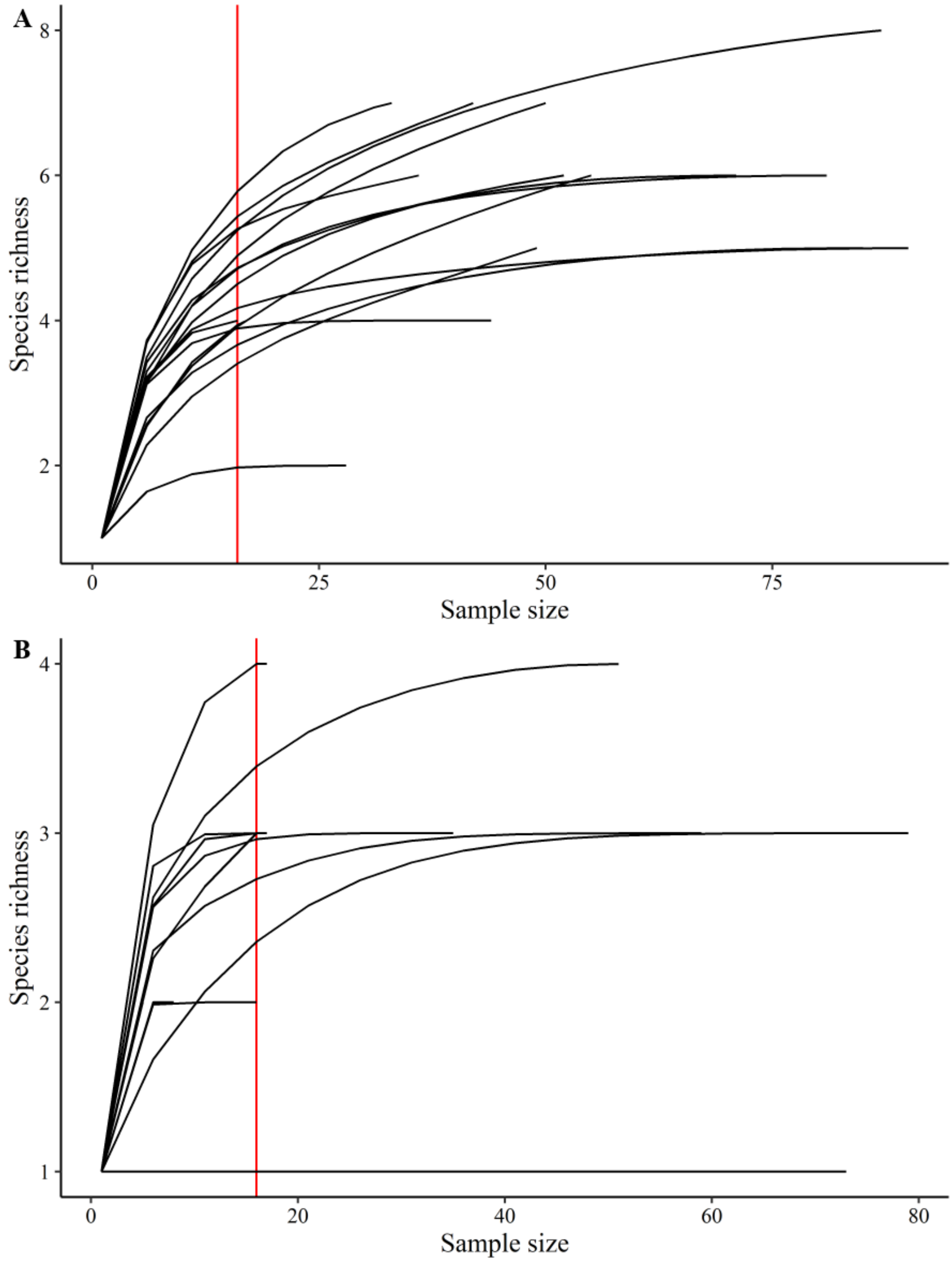

Figure 4: Species accumulation curves showing species accumulation at different sampling efforts for dragonflies (A) and damselflies (B).

Species Abundance, Diversity and Richness in Site Categories

The study sites were categorised into 3 groups based on the Habitat integrity Index (HII) calculated. On the overall, the index calculated for sites within the Metropolis ranged from 0.212 to 0.758. Five sites were categorised as highly disturbed, 7 sites were categorised as moderately disturbed and 4 sites were categorised as least disturbed (Table 7).

Table 7: Habitat Integrity Index (HII) Calculated for each Habitat within the Cape Coast Metropolis

Site	HII	Condition
Duakor	0.242	Highly disturbed
Apewosika	0.212	Highly disturbed
Science	0.606	Moderately disturbed
Kwaprow	0.727	Least disturbed
Akotokyir	0.636	Moderately disturbed
UCC Farm	0.667	Moderately disturbed
Adisadel Estate	0.303	Highly disturbed
Fosu Lagoon	0.303	Highly disturbed
Adisadel Village	0.212	Highly disturbed
Adisadel College	0.606	Moderately disturbed
Antem	0.424	Moderately disturbed
UPSHS	0.697	Moderately disturbed
Bonkus	0.545	Moderately disturbed
Kakumdo	0.758	Least disturbed
Esuekyir	0.758	Least disturbed
Efutu	0.727	Least disturbed

Least disturbed (0.7 – 1.0); Moderately disturbed (0.4 – 0.69); Highly disturbed (0.0 – 0.39).

The total species abundances between the site categories were compared to ascertain the differences between the site categories. The difference in overall abundance of all dragonflies (Kruskal-Wallis chi squared (2) = 3.0041, p = 0.2227) and damselfly (Kruskal-Wallis chi squared (2) = 3.1902, p = 0.2028) species was not significant between the site categories (Figure 5).

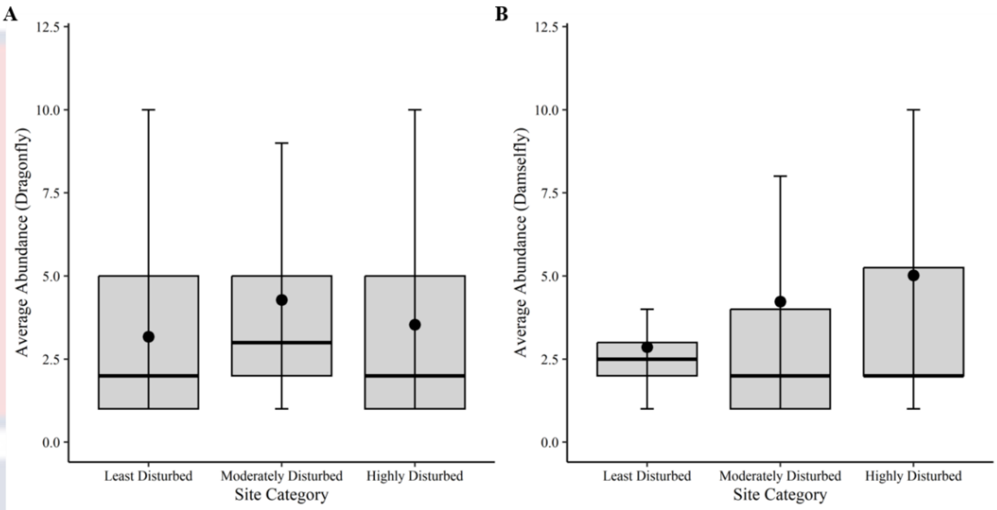

Figure 5: Box plot of the abundance of dragonflies (A) and damselflies (B) recorded within the habitat categories.

Site categories showed significant differences between the diversity of dragonflies (Kruskal-Wallis chi squared (2) = 52.836, $p < 0.05$) and damselflies (Kruskal-Wallis chi squared (2) = 24.241, $p < 0.05$). However, post-hoc test conducted for pairwise comparison showed significant differences between the diversity of dragonflies in highly disturbed and moderately disturbed sites ($p < 0.05$) and between least disturbed sites and moderately disturbed sites ($p < 0.05$) (Figure 6A). Similarly, a significant difference was observed between the diversity of damselflies in highly disturbed and moderately disturbed sites ($p < 0.05$) (Figure 6B).

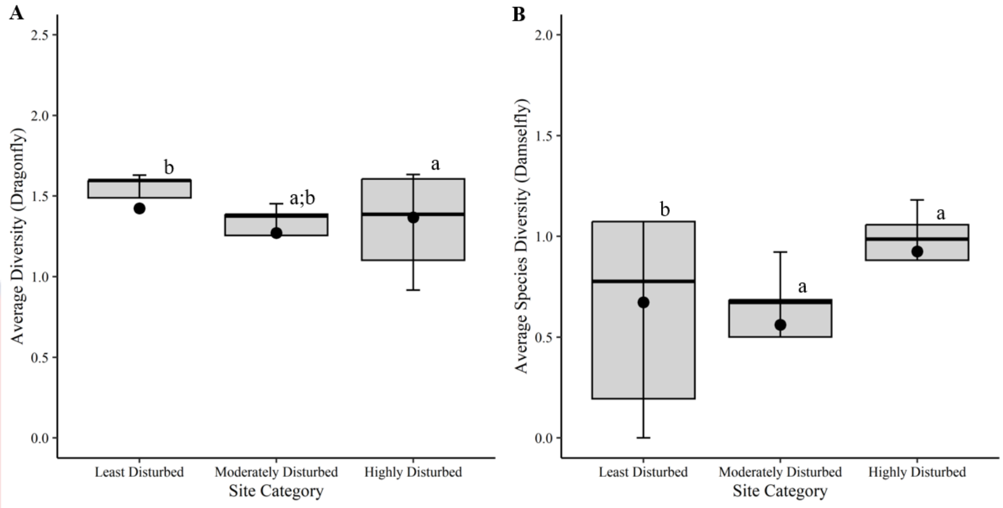

Figure 6: Box plot of the average species diversity of dragonflies (A) and damselflies (B) recorded for sites within each site category.

A significant difference was also observed for species richness for dragonflies (Kruskal-Wallis chi squared (2) = 18.981, $p < 0.05$) and damselflies (Kruskal-Wallis chi squared (2) = 56.573, $p < 0.05$) between the site categories (Figure 7). Post hoc test showed a significant difference for dragonfly richness between least disturbed sites and moderately disturbed sites ($p < 0.05$). Similarly, a significant difference was observed for damselfly richness between highly disturbed sites and moderately disturbed sites ($p < 0.05$) as well as between highly disturbed sites and least disturbed sites ($p < 0.05$).

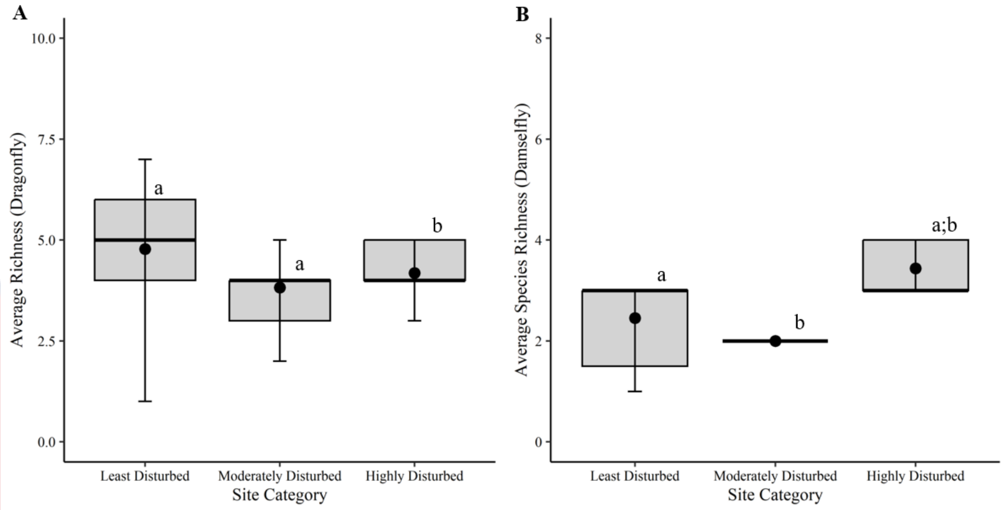

Figure 7: Box plot of the average species richness of dragonflies (A) and damselflies (B) recorded for sites within each site category.

Local Climatic Characteristics of Study Sites

Temperature, windspeed, humidity, light intensity, water temperature and pH were measured as local climatic variables at each study site. The average atmospheric temperature of the study sites ranged from 30.5 ± 3.87 to 36.2 ± 4.55 (mean ± sd) across the study sites. The average atmospheric temperature recorded at highly disturbed sites was significantly lower than at moderately disturbed sites (p = 0.02) (Figure 8A). Atmospheric temperature across the sites was relatively higher as compared to water temperature. The average water temperature across the study sites ranged from 24.0 ± 0.21 to 34.4 ± 1.71°C (mean ± sd). Significant differences were observed between the average water temperature of Highly disturbed sites and least disturbed sites (p = 0.00), and moderately disturbed sites (p = 0.00) as well as between moderately disturbed sites and least disturbed sites (p = 0.003) (Figure 8B).

Light intensity also varied across sites. The average light intensity recorded ranged from 23.6 ± 3.09 to 81.2 ± 4.84 Klux (mean ± sd) and was significantly higher at moderately disturbed sites than at least disturbed sites (p

= 0.002) (Figure 9A). Average humidity also ranged from 66.2 ± 8.66 to 81.6 ± 4.84% (mean ± sd) across the study sites and was significantly higher at highly disturbed sites than at least disturbed sites (*p* = 0.00) and at moderately disturbed sites (*p* = 0.00) (Figure 9B). The pH of water bodies sampled within the Metropolis were slightly basic with values ranging from 7.2 to 8.5. The difference in pH was not significant between the sites (Figure 9C).

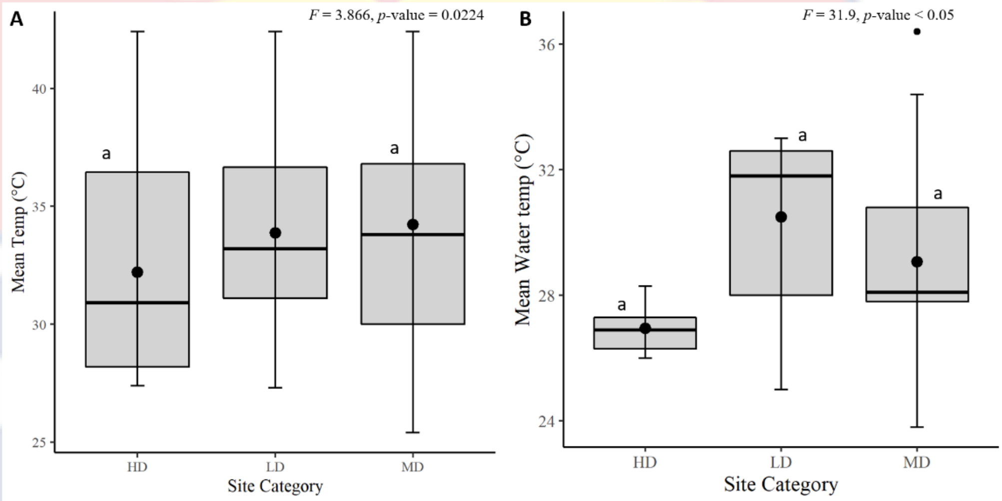

Figure 8: Mean atmospheric temperature (A) and water temperature (B) recorded across the site categories (HD - Highly disturbed, MD- Moderately disturbed, LD – Least disturbed)

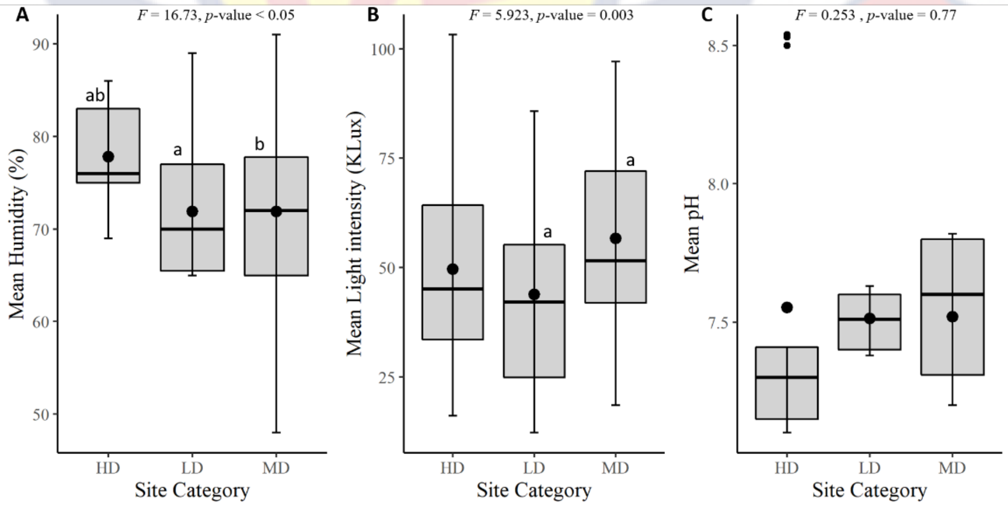

Figure 9: Mean humidity (A), light intensity (B) and pH (C) across site categories (HD - Highly disturbed, MD- Moderately disturbed, LD – Least disturbed)

Effects of Local Climate and Habitat Characteristics on Species Compositions

Non-metric multidimensional scaling (NMDS) plots were used to visualise species compositions of dragonflies and damselflies between the three site categories (Figure 10). NMDS plots for damselflies show that highly disturbed sites were similar in their species compositions as compared to least disturbed sites and moderately disturbed sites. Least disturbed sites also showed more similarity in species compositions as compared to highly moderately disturbed sites, which showed a wide variation in species compositions. Highly disturbed sites were mostly characterised by higher abundances of *Agriocnemis zerafica* (AGZE) and *Ceriagrion sp* (CESP), while least disturbed sites were characterised by higher abundances of *Allocnemis sp* (ALSP) and *Phaon camerunensis* (PHCA). Some moderately disturbed sites were however characterised by higher abundances of *Allocnemis ellongata* (ALEL), *Chlorocypha curta* (CLCU) as well as *Ischnura senegalensis* (ISSE) (Figure 10B). The differences in damselfly species compositions across the site categories were however not significant (R^2 = 0.231, PERMANOVA = .0.067)

NMDS plots for dragonfly species compositions showed that sites were varying. Each site in each category appears to have a different set of species that dominated within that site (Figure 10). Some species such as *Brachythemis leucostica* (BRLE), *Brachythemis impartita* (BRIM), *Bradinopyga strachani* (BRST), *Acisoma inflatum* (ACIN) and *Diplacodes lefebvrii* (DILE) were more associated to highly disturbed sites. On the other hand, *Trithemis arteriosa* (TRAT), *Triithemis sp* (TRSP), *Aescithemis sp* (AESP), *Paragomphus serrulatus* (PASE) and *Palpopleura portia* appeared to be more associated with moderately disturbed sites. *Anax Tristis* (ANTR) was the only species that showed a clear association with least disturbed sites (Figure 10A). The difference is dragonfly compositions across the categories was also not significant (R^2 = 0.127, PERMANOVA = .0.067).

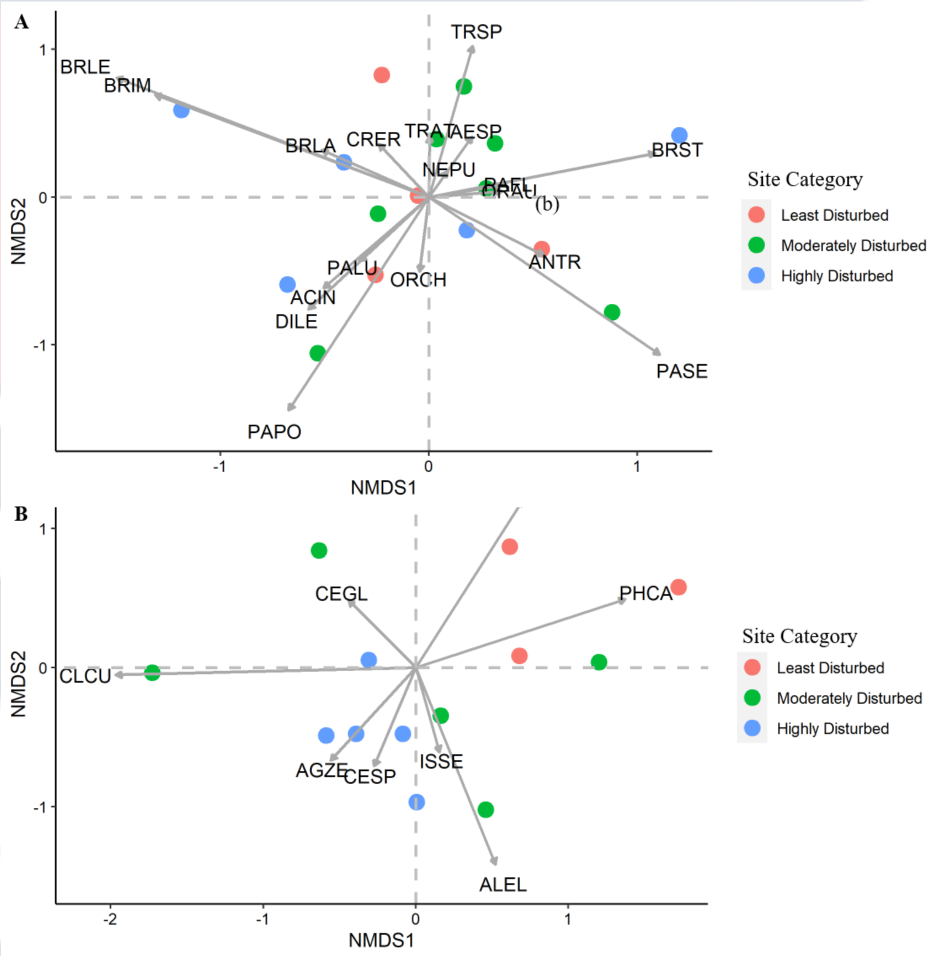

Figure 10: Non-metric multidimensional scaling plot showing dragonfly (A) and damselfly (B) species compositions in each site category.

Redundancy analysis was conducted to test for the effects of local climate and habitat characteristics on compositions of dragonflies and damselflies across the site categories. Redundancy analysis showed that habitat characteristics explained about 72% of damselfly compositions across the habitat categories. Results of the redundancy analysis also showed that the condition of the riparian vegetation was more important for damselfly compositions across the three levels of disturbance (Table 14).

Table 8: Redundancy analysis of the effects of local climate and habitat characteristics on damselfly species compositions across site categories

	Inertia	Proportion	Rank
Total	603.12	1	
Constrained	433.84	0.719	7
Unconstrained	169.40	0.281	8
Variable	**Variance**	**F**	**Pr(>F)**
Atmospheric Temperature	32.681	1.5437	0.243
Wind speed	9.611	0.454	0.577
pH	12.211	0.5768	0.463
Preservation of riparian veg.	18.374	0.8679	0.422
Condition of riparian veg.	298.274	14.0889	0.004*
Water retention mech.	9.826	0.4641	0.589
Cropland	52.764	2.4923	0.142

Eighty-eight percent of the variations in dragonfly composition was explained by the measured habitat characteristics. However, none of the variables showed significant importance for dragonfly assemblages (Table 15).

Table 9: Redundancy Analysis of the Effects of Local Climate and Habitat Characteristics on Species Composition of Dragonflies Across the Site Categories

	Inertia	Proportion	Rank
Total	626.617	1	
Constrained	555.458	0.886	12
Unconstrained	71.159	0.114	3
Variable	**Variance**	**F**	**Pr(>F)**
Atmospheric Temperature	25.2	0.6327	0.687
Wind speed	11.77	0.2956	0.947
pH	133.19	3.344	0.054
Preservation of riparian veg.	36.13	0.9071	0.495
Condition of riparian veg.	59.7	1.4988	0.232
Water retention mech.	23.3	0.5849	0.735
Cropland	18.69	0.4692	0.826

Effect of Local Climate and Habitat Characteristics on Species Diversity, Abundance and Richness

Local climatic variables and the physical characteristics measured were tested for multicollinearity thus the effects of variables that were correlated with each other ($r < \pm 0.5$) were not tested.

Effect on species abundance

Generalised linear mixed effect model showed varying effects of local climatic variables and habitat characteristics in the abundance of dragonflies and damselflies. Generally, atmospheric temperature, pH, and preservation of riparian vegetation showed positive effects on the abundance of damselflies. Wind speed, condition of the riparian vegetation, water retention mechanism, and cropland showed negative effects on the abundance of damselflies. Despite the effects observed by the variables, the condition of the riparian vegetation, showed significant effects on the abundance of damselflies.

On the other hand, the abundance of dragonflies was positively affected by atmospheric temperature and pH, and was negatively affected by wind speed, preservation of riparian vegetation, condition of riparian vegetation, water retention mechanism and cropland. pH of water showed significant effect on the abundance of dragonflies.

Effect on species richness

The results of the Linear mixed effect model showed that Atmospheric temperature, presence or absence of cropland, condition and preservation of the riparian vegetation had negative effects on the richness of damselflies but the effect of only preservation of the riparian vegetation was significant. The remaining variables showed positive effects on damselfly richness.

For dragonflies, temperature showed a significant positive effect on diversity, while wind speed, preservation and condition of the riparian vegetation showed negative effects but their effects were not significant. The remaining variables showed positive effects on dragonfly richness at the study sites.

Effect on species diversity

Linear mixed effect model showed effects of local climate and habitat characteristics on species diversity of dragonflies and damselflies. The preservation of riparian vegetation and water retention mechanism showed significant effect on the diversity of damselflies recorded at the study sites. Preservation of riparian vegetation and atmospheric temperature showed negative effects while the remaining variables showed positive effects on the diversity of damselflies recorded at the study sites.

Dragonfly diversity was also significantly affected by preservation of riparian vegetation, condition of riparian vegetation, the presence or absence of cropland, and water retention mechanism. The effects water retention mechanism and the presence or absence of cropland were positive. (See appendix G for detailed model output).

Dragonfly Biotic Index

Based on the distribution of dragonflies and damselflies as well as the differences in their sensitivities across the sites and different levels of disturbance, a dragonfly biotic index was developed to assess the integrity of freshwater habitats within the Metropolis. The scores of the distributions of the species showed variations between the distributions of the species. Whereas some species were widespread (score of 0), others were limited to few sites (3) or intermediates (scores of 1 and 2). All species recorded were “least concerned” based on the IUCN threat category. The sensitivity scores of species ranged between 0 and 2. Based on the distribution scores, threat scores, sensitivity scores and overall DBI for each species were calculated.

Chlorocypha curta, *Phaon Camerunensis*, *Anax tristis*, *Nesciothemis pujoli*, *Palpopleura portia*, *Paragomphus serrulatus*, and *Trithemis sp*. recorded the highest DBI scores. *Ischnura senegalensis*, *Orthetrum chrysostigma*, and *Palpopleura lucia* recorded the lowest DBI scores (Table 16).

Table 10: Distribution Based Scores (DBS), Threat Based Scores (TBS), Sensitivity Based Scores (SBS) and overall Dragonfly Biotic Index (DBI) of each species recorded in the Cape Coast Metropolis

Sub order	Species	DBS	TBS	SBS	DBI
Zygoptera	*Agriocnemis zerafica*	3	0	0	3
Damselflies	*Allocnemis ellongata*	3	0	1	4
	Allocnemis sp	3	0	1	4
	Ceragrion sp	2	0	0	2
	Ceriagrion glabrum	0	0	0	0
	Chlorocypha curta	3	0	2	5
	Ischnura senegalensis	1	0	0	1
	Phaon Camerunensis	3	0	2	5
Anisoptera	*Acisoma inflatum*	1	0	1	2
Dragonflies	*Aethiothemis spp*	2	0	1	3
	Anax tritis	3	0	2	5
	Brachythemis impartita	3	0	0	3
	Brachythemis lacustris	3	0	0	3
	Brachythemis leucostica	3	0	0	3
	Bradinopyga strachani	2	0	0	2
	Crocothemis erythrae	1	0	1	2
	Diplacodes lefebvrii	3	0	0	3
	Nesciothemis pujoli	3	0	2	5
	Orthetrum austeni	2	0	1	3
	Orthetrum chryostigma	1	0	0	1
	Palpopleura lucia	1	0	0	1
	Palpopleura portia	3	0	2	5
	Pantala flavescens	3	0	1	4
	Paragomphus serrulatus	3	0	2	5
	Trithemis arteriosa	0	0	0	0
	Trithemis sp	3	0	2	5

Species DBI's were used to determine the overall DBI for each site. Site DBI's calculated ranged from 1.0 to 2.3 out of the maximum possible score of

9 (Table 17). Kakumdo, and Esuekyir recorded the highest DBI's followed by Kwaprow and Akotokyir. UPSHS recorded the lowest site DBI (Table 17).

Table 11: Sum of species DBI, number of species and Overall Site DBI Calculated for Each Site

Site	Sum of Species DBI	No. of Species	Overall Site DBI
Adisadel Estate	16	10	1.6
Adisadel College	16	8	2.0
Adisadel Village	17	10	1.7
Akotokyir	13	6	2.2
Antem	14	9	1.6
Apewosika	10	7	1.4
Bonkus	17	8	2.1
Duakor	17	10	1.7
Efutu	9	7	1.3
Esuekyir	7	3	2.3
Fosu Lagoon	12	8	1.5
Kakumdo	25	11	2.3
Kwaprow	22	10	2.2
Science	15	8	1.9
UCC Farm	9	5	1.8
UPSHS	6	6	1.0

To evaluate the robustness of the DBI, it was compared with the habitat integrity index as recorded in this study. Regression model showed a positive relationship between the DBI and the HII (Figure 11). Furthermore, the DBI explained 15% of the variation observed in the Habitat Integrity Index (R^2 = 0.15, y = 0.147 + 0.212x).

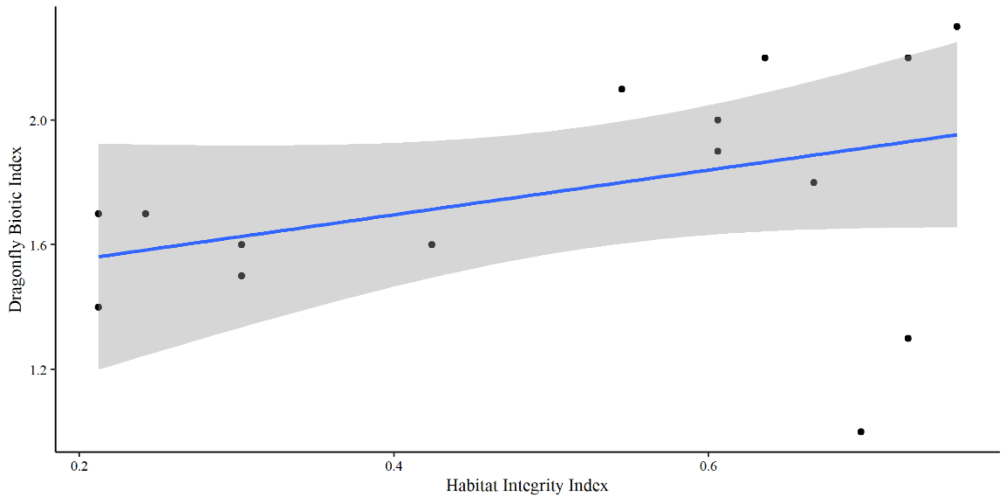

Figure 11**:** Output of linear regression model showing the relationship between dragonfly biotic index and habitat integrity index.

CHAPTER FIVE

DISCUSSION

This chapter discusses the results of the study. The findings and observations made in this study are compared with reports in literature to provide support and evidence for the findings of this study. Explanations for the findings are also provided based on the objectives of the study.

Diversity and Abundance of Dragonflies and Damselflies in the Cape Coast Metropolis

The Odonata are a group of insects that show high diversity in habitat preference (Monteiro Júnior *et al.*, 2015; Simaika & Samways, 2009; Wildermuth, 2010) and as such, the expectation is that a wide range of species may exist in a given area. In this study, 26 species of dragonflies and damselflies from different locations and water body types in the Metropolis were recorded. In comparison to the Odonata species checklist by Dijkstra, (2007), these 26 species represent 14.7% of the total species, 13.8% of damselflies, and 13.4% of dragonflies recorded in Ghana. Species abundance in the Metropolis was less as compared to other areas surveyed in Ghana. However, those studies surveyed areas that were a matrix of forest areas, farmlands, botanical gardens and residential areas (Acquah-Lamptey *et al.*, 2013a, 2013b; Seidu *et al.*, 2017, 2018, 2019, 2020). This study was conducted in an urban area which may be the reason for the low number of species recorded.

The species recorded in the Metropolis also belonged to 7 families. The dominant families were Coenagrionidae and Libellulidae for dragonflies and damselflies respectively. Record of species present in Ghana show that most dragonflies and damselflies belong to the families Coenagrionidae and

Libellulidae respectively (Dijkstra, 2007). Globally, the two families comprise the most abundant Odonata families with highly diverse species compositions and habitat preferences. This may account for why most species of dragonflies and damselflies recorded in this study belonged to these families. Earlier studies also show the dominance of these two families in most areas that have been surveyed in Ghana (Acquah-Lamptey *et al.*, 2013a; Seidu *et al.*, 2017, 2018, 2019). Moreover, dragonflies of the families, Gomphidae and Aeshnidae often prefer cleaner and less disturbed habitats and are very sensitive to changes in habitats (Ameilia *et al.*, 2006; Dijkstra & Clausnitzer, 2014). They are also known to generally have a low reproductive rate and as such do not occur in large numbers (Dijkstra & Clausnitzer, 2014).

Generally, forest areas and natural habitats have been observed to host more species than urban areas. Furthermore, species present in non-urban areas are often habitat specialists with majority of species in urban areas being habitat generalists (Lososová *et al.*, 2012; Sol *et al.*, 2014). This trend was observed in this study as well. Most of the species recorded in this study can be said to be generalists with preference for different habitat conditions and water body types. According to the habitat descriptions of species adapted from the African Dragonfly and Damselfly database (ADDO) (Kipping *et al.*, 2009), *Phaon camerunensis*, *Allocnemis ellongata*, *Paragomphus serrulatus*, and *Orthetrum austeni* are forest specialists and are mostly found in forest landscapes. These species were recorded in the Metropolis despite the area not being a forest area. Characteristics of the study sites showed that sites harbouring these specialist species had shady large trees and vegetation types. Perhaps, habitat preference for these species extend beyond forest characteristics to rather specific habitat conditions surrounding the water body.

The other species had wider range of habitat preferences and were classified as non-specialists and their habitat descriptions often include either open landscapes only, or a combination of open landscapes and forest areas. Though some species are described as generalists, they showed preference for some specific habitat types. For instance, *Chlorocypha curta* is described as a generalist species (Kipping *et al.*, 2009) but was recorded in only one site within the Metropolis. This site was characterised by a high canopy cover and a preserved riparian vegetation with the vegetation mainly comprising of matured trees. This was also the case for *Allocnemis zerafica*, and *Anax tristis*. This implies that even within urban species, the preference for habitat types differ. The findings of the study provide evidence for the role of urban areas in supporting different species of dragonflies and damselflies.

The species recorded in this study also showed preference for different water body types. *Brachythemis leucostica* and *Brachythemis impartita* were recorded in the lagoon habitat. This is in line with habitat descriptions of the species as described by the ADDO (Kipping *et al.*, 2009). Aside the preference to water body types, species also showed preference to different levels of disturbance as assessed in this study. It is indeed the case that dragonflies and damselflies show variations in habitat types and habitat requirements, even in urban areas. The findings of this study are therefore in line with the general observations (Clark & Samways, 1996; Samways & Steytler, 1996; Silva *et al.*, 2010).

The most abundant damselfly and dragonfly recorded in the Metropolis was *Ceriagrion glabrum* and *Trithemis arteriosa* respectively. These species were found in majority of habitats that were surveyed in the Metropolis. Though other studies have recorded these species in Ghana, they were not dominant in the areas that were surveyed. Other species that showed higher abundances included *Orthetrum chrysostigma* and *Ischnura senegalensis.* These species are typically urban (Kipping *et al.*, 2009) therefore it is not unusual to find them in the Metropolis. *Ischnura senegalensis*, a generalist, for instance has been recorded to breed in organically polluted waters and are able to tolerate high amounts of disturbance (Deacon and Samways, 2021). Species preference to habitats are however determined by the set of prevailing conditions that exists in an area. Therefore, it can be said that the Cape Coast Metropolis provides a suitable condition for the survival and reproduction of these species.

Studies have also shown that dragonflies and damselflies have different habitat requirements owing to differences in their eco-physiological needs (Šigutová *et al.*, 2019). Whereas damselflies are more susceptible to overheating and thus show more preference for natural and preserved habitats with little tolerance to habitat disturbance (Corbet, 1999; McCauley, 2006; Dolný *et al.*, 2012), the majority of dragonflies prefer open areas due to their ability to regulate temperature (Corbet, 1999; McCauley, 2007). The habitat integrity index of the sites showed that all sites experienced some level of disturbance. This explains the lower number of species of damselflies than dragonflies recorded within the Metropolis. The differences in the number of species of dragonflies and damselflies in this study are in line with earlier findings (Monteiro-Júnior *et al.*, 2014; Monteiro Júnior *et al.*, 2015; Luke *et al.*, 2017; Seidu *et al.*, 2017, 2018).

Effect of Habitat Conditions on Odonata Assemblages in Freshwater Habitats

In order explain the differences in the species presence or absence as well as abundances in the study sites, it is important that the set of characteristics that define the sites are assessed and their effects measured. As such, the study recorded the microclimatic conditions and the physical habitat characteristics of the study sites. Study sites assessed in this study showed significant differences in microclimatic conditions and different scores for the physical habitat characteristics indicating different characteristics for the study sites. The differences were supported by the HII scores recorded for each site. Sites within the Metropolis were categorised into least, moderate and high level of disturbance reflecting the degree of disturbance of human activities on the study sites. According to Monteiro-Júnior *et al.* (2014), the HII is effective at assessing the impacts of urbanisation on freshwater habitats. Although local climatic conditions were not assessed as variables in the HII, Couceiro *et al.* (2007) have shown that HII scores are consistent with local climatic conditions such as atmospheric temperature and pH (Monteiro-Júnior *et al.*, 2014).

Findings from the study showed negative relationships between HII and the diversity and richness of dragonflies and damselflies but showed a positive relationship with the abundance of dragonflies. This relationship supports the finding that the species present within the Metropolis are generalists as such they prefer more disturbed sites to less disturbed sites. The observed relationship however differed from the findings of Monteiro-Júnior *et al.* (2014)

who observed a positive relationship between the richness and abundance of damselflies and the habitat integrity, and a negative relationship between the richness and abundance of dragonflies and the habitat integrity.

The activities of humans have both direct and indirect effects on the integrity of freshwater habitats as well as other aquatic ecosystems (Deacon & Samways, 2021). These activities, including the infilling and drainage of water bodies (Allan, 2004; New, 2015), dumping of refuse, clearing of vegetation for agriculture and development, among others (Deacon & Samways, 2021), are often conducted on the terrestrial environment but their effects are also felt within the aquatic ecosystems. Damselflies and dragonflies are sensitive to the changes in the local environment caused by these activities and it has been shown that modifications to both the terrestrial and aquatic habitats have implications for the survival and reproduction of the Odonata (Deacon & Samways, 2021). For instance, materials that contaminate freshwater habitats often originate from run-off water from the terrestrial habitat into the aquatic habitat (Paul & Meyer, 2001; Camargo & Alonso, 2006; Tixier *et al.*, 2011). These contaminants change the physicochemical properties of water including the water temperature and pH (Paul & Meyer, 2001; Frost *et al.*, 2015). Results from this study showed that dragonfly abundance in the site categories were significantly affected by the pH of the water. This indicates that species may be sensitive to different pH levels (Da Rocha *et al.*, 2016). It was observed in this study that *Brachythemis impartita* and *Brachythemis leucostica* were associated more with higher pH as compared to the other species. pH was however not important for damselfly diversity, richness, abundance and compositions.

The presence of dumping sites along the study sites was correlated with the presence or absence of human occupation and the presence or absence of domestic and industrial waste. It was observed that most communities situated along the study sites preferred to use the water body as dumping sites thereby contributing to the disturbance of the site. The practice of dumping refuse in water bodies is common among many urban areas in Ghana (Adzawla *et al*., 2019; Kodua & Anaman, 2020). Resident do that in anticipation that heavy rains would carry away the refuse. As such, water bodies that are generally disturbed may receive refuse from upstream waters that are highly disturbed. Indicators of refuse including plastics, metal, glass, rubber, building materials, and organic matter were recorded as materials that impede the flow of water. The water retention mechanism was significant for the diversity of dragonflies and damselflies. Sites with less indication of the presence of refuse recorded higher diversities than sites with more waste materials. Similar findings were reported by Henriques-de-Oliveira *et al.* (2007) and Solimini *et al.* (1997).

Aside the conditions present within the water, the surrounding vegetation also significantly influences the presence or absence of dragonflies and damselflies. For instance, endophytic damselfly and dragonfly species oviposit in submerged and surrounding vegetation and their larvae hide from prey and predators under the submerged vegetation. Adult dragonflies and damselflies also perch on surrounding vegetation between flight and also during hunting for prey (Corbet, 1980). Newly emerged adult damselfly and dragonfly often fly away from the water habitat and only return when reproductively matured (Smith *et al*., 2009). During this period, they roost in surrounding vegetation including dense bushes (Heymer, 1964) and low lying grasses (Parr

& Marrion, 1974; Hassan, 1976). The type and extent of surrounding vegetation along a freshwater habitat is therefore important for survival and reproduction of many damselfly and dragonfly species as shown in this study.

The presence of riparian vegetation was important for the diversity of dragonflies and damselflies and for the richness of damselflies. Sites with intact vegetation along both sides of the water body recorded lower diversities of dragonflies and damselflies and more few of damselflies. It has been shown that the presence or absence of riparian vegetation is a better predictor of Odonata species presence as compared to water conditions (Urban *et al*., 2006; Deacon, Samways, & Pryke, 2018). The loss of vegetation limits the movement of Odonata and reduces connectivity to other habitats (Deacon & Samways, 2021). This may explain the negative effect of preservation of the riparian vegetation observed in this study. Perhaps, due to the absence of connectivity, species have been localised and as such were encountered frequently. It is possible that some species may hide within the surrounding vegetation, as has been observed as a behaviour of damselflies (Cezário *et al.*, 2020), and were not sighted.

The condition of the riparian vegetation was also important for the abundance of damselflies as well as for the diversity and richness of dragonflies and its composition of damselfly species along the disturbance gradient. The riparian vegetation along most of the sites surveyed comprised of grasses and shrubs, a matrix of grasses and pioneer trees with regenerating habitat and pioneer species present along few sites, corresponding to a decreasing level of disturbance. The expectation is that riparian vegetation comprising of native or natural plant communities would support more species but the opposite was observed in this study. This is explained by the presence of more generalists within the Metropolis as compared to specialists. Similar findings were made by (Briggs *et al*., 2019; Vilenica *et al*., 2020) where a decline in dragonfly diversity was recorded in habitats with dense riparian vegetation. Riparian vegetation may be important the type of vegetation matters. Studies have shown that alien vegetation that may replace native vegetation have negative effects on the presence of dragonflies and damselflies (Deacon & Samways, 2021).

The loss of riparian vegetation may also be caused by construction of infrastructure including buildings, dams and roads, among others (Deacon & Samways, 2021). Roads for instance have been recorded to affect dragonflies (New, 2015) by limiting movement between favourable habitats (Muñoz *et al*., 2015). As such, it has been suggested that construction of roads through dragonfly habitats must be avoided (Riffell, 1999).

The presence of cropland showed significant effect on the diversity of dragonflies but not on damselflies. The presence of cropland supported a diverse community of dragonflies. Even though agriculture is generally known to have a negative effect on dragonfly diversity (Raebel *et al*., 2012), some studies have shown that some farms may house more diverse community of dragonflies (Baba *et al*., 2019). Temperature also showed significant positive effect on the richness of dragonflies which can be explained by higher temperature requirement of most dragonfly species hence their preference for more opened spaces.

Developing a Local Based Dragonfly Biotic Index to Assess the Integrity of Freshwater Habitats

A Dragonfly Biotic Index (DBI) was developed based on the species recorded, species sensitivity to different levels of disturbance, distribution within the Metropolis as well as threat category as sub-indices of the DBI. The index was adopted from a DBI for South Africa (Simaika & Samways, 2009). This was necessary because the conditions present and the factors that affect dragonflies and damselflies may differ between geographical regions. This index however cannot be applied to assess the habitat integrity of freshwater bodies across the country. For that to be done, a complete list of the species in Ghana, their distribution, and habitat preference as well as their threat status must be assessed to provide enough information for a national scale assessment. As more species become known in the Metropolis, the index may be updated to include the new available information to ensure a comprehensive assessment tool.

The dragonfly biotic index has been recommended as a suitable tool and a good substitute for assessing the integrity of freshwater habitats (Simaika & Samways, 2009; Samways & Simaika, 2016; Uyizeye, 2020; Vorster *et al.*, 2020). The sub-indices of the index help to identify species that require more priority for conservation and in effect the sites that require more conservation action (Uyizeye, 2020). Generally, species that are widespread and tolerant to disturbance are poor predictors of the integrity of a habitat while species that are restricted to certain habitat types and are sensitive to disturbances are better indicators of the quality of the freshwater habitat. The DBI calculated for the species clearly showed habitat specialists and generalists within the Cape Coast Metropolis. Despite all species recorded having a "least concerned" threat status, specialists are under threat of being removed from the Metropolis. *Chlorocypha curta*, *Phaon Camerunensis*, *Anax tristis*, *Nesciothemis pujoli*, *Palpopleura portia*, *Paragomphus serrulatus*, and *Trithemis sp* recorded the highest species DBI due to their restricted habitat and sensitivity to disturbance. Further disturbance to these sites higher than what is experienced at the moment could remove these species from the Metropolis.

The overall DBI for each habitat calculated showed that all the sites surveyed within the Metropolis have poor conditions as habitats for a wide range of Odonata species. This is because more generalists were recorded than specialists across the Metropolis. For a site to have a high DBI, the site should be able to support a wide range of species that are sensitive to habitat disturbance. Comparatively, some sites showed better conditions at hosting sensitive species thus have higher site DBI's as compared to sites with lower DBI's. Factors that showed significant effects on the abundance, diversity and composition must be addressed to mitigate the impacts of human activities on freshwater habitats within the Metropolis in order to protect Odonate assemblages as well as other aquatic flora and fauna.

The DBI can effectively replace the Habitat Integrity Index (HII) and provides a faster tool for assessing the habitat integrity of freshwater habitats. The efficiency of the DBI is supported by the positive correlation observed between the DBI and HII. Sites with higher DBI recorded higher HII. Even though there were few exceptions to this relationship, the index can be said to be reliable. The HII captured all the possible factors that may influence the habitat's integrity thus a positive relationship of the DBI with the HII supports the robustness of the DBI.

The use of the DBI to assess the integrity of habitat is supported by the recommendation of using several species as indicators rather than a single species (Villéger, 2008; Alsterberg *et al.*, 2017). The use of a single species as bioindicator is not reliable due to the potential to skew results. The use of species assemblages shows better accuracy of determining the ecological integrity of a habitat (Berquier *et al*., 2016; Miguel *et al*., 2017). The inherent preference of Odonata to different habitat conditions at the species level also contribute to the robustness of the DBI (Samways & Simaika, 2016). The survey was also conducted across the rainy and dry season therefore seasonal variations in species compositions have been captured in developing the DBI as recommended by (Samways & Grant, 2007).

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents a summary of the entire study and highlights the key points that were addressed. The conclusions drawn from the findings of the study are also presented in the chapter. Recommendations for further studies as well as practical applications of the findings of this study are also provided in this chapter.

Summary

In this study, the effects of habitat disturbance on Odonate assemblages were investigated. Damselflies and dragonflies were collected from 16 sites categorised into three levels of disturbance within the Metropolis Twenty-six species of dragonflies and damselflies were recorded within the Cape Coast Metropolis. The results of the analysis of the data collected showed significant differences in the local climatic variables measured across the study sites except pH. Generalised linear mixed effect model showed a significant effect of pH on the abundance of dragonflies, and the water retention mechanism on dragonfly abundance, and the condition of the riparian vegetation on damselfly abundance. The diversity of dragonflies and damselflies was also significantly affected by the preservation of the riparian vegetation, and the water retention mechanism. Preservation of the riparian vegetation and Temperature showed significant effects on species richness of dragonflies and damselflies respectively. Redundancy analysis also showed that the condition of the riparian vegetation was significant in determining dragonfly and damselfly compositions across the 3 levels of habitat disturbance.

The findings of the study show that freshwater habitats within the Metropolis are disturbed by a number of human associated activities which affects the abundance of dragonflies and damselflies. To assess the integrity of freshwater habitats within the Metropolis, the dragonfly biotic index developed for the Metropolis can be applied instead of using the Habitat Integrity Index. The efficiency of the dragonfly biotic index was shown by the positive relationship observed between the index and the habitat integrity index measured. The DBI provides a faster and reliable tool for habitat assessment.

Conclusions

In conclusion, the study recorded 26 species from the Metropolis. Different levels of disturbance showed differences in Odonata diversities and richness however the differences in abundance was not significant indicating the importance of species diversity and richness as tools for measuring habitat conditions. Key variables important for the survival of urban dragonflies and damselflies include the condition and preservation of the riparian vegetation as well as the water retention mechanism. pH, temperature and presence of cropland were also important for urban dragonflies. Freshwater habitats within the metropolis are disturbed as shown by the Habitat Integrity Index and the Dragonfly Biotic Index. Nevertheless, the metropolis has the potential to support more species, both generalists and specialists, if conditions are improved.

Recommendations

Based on the findings of the study, it is recommended that, additional surveys are conducted to ascertain the extent of species present within the Metropolis. Based on the sampling protocol, all potential habitats including temporary waters, minor streams and ponds were not sampled. It is therefore possible that there were other species which were not captured in this study. It is therefore recommended that; all other water bodies should be surveyed. This is important because the calculated diversity estimates suggest the potential presence of about 36 species.

It is also recommended that similar studies be conducted in other urban areas in Ghana to capture the differences in the factors that may influence the presence or absence of dragonflies and damselflies in urban areas. The findings of this study and recommended studies can help in city planning by the Town and Country Planning departments of the Local governments to ensure that biodiversity is protected in the wake of increasing urbanisation. Such further studies will also add to the knowledge on the distribution and habitat preference of species as well as their sensitivities to different levels of disturbance. More knowledge in these areas is required to draw up a national Dragonfly Biotic Index which can be applied to habitat assessments on a larger scale. A national red list of Odonata is also needed as the country currently lacks one.

Specifically, in the Cape Coast Metropolis, urban green centres and biodiversity hotspots can be created in addition to protecting freshwater habitats in other to add to the already existing recreational facilities and tourist sites. As such, it is recommended that efforts are put in place to protect freshwater habitats within the Metropolis from further disturbance. It is therefore recommended that overall sanitation conditions should be improved within the Metropolis especially with respect to dumping of refuse, especially, in water ways. Also, margins of riparian vegetation should be conserved along freshwater habitats as buffers to factors that may disturb the habitat.

Even though riparian vegetation is important for conserving aquatic biodiversity, the type of vegetation may be important. It is recommended that further studies are conducted to investigate the association between plant species communities and Odonate assemblages.

Based on the results of the DBI, conservation efforts are required to restore the integrity of the habitats surveyed and the entire Metropolis. To assess the success of conservation actions, the DBI can be assessed after restoration efforts.

Urbanisation is a continuous process and so its effects can only be mitigated if urban spaces are planned prior to development. It is therefore recommended that further development of areas should consider the potential impacts on biodiversity and implement measures that would reduce the effect of the development on the environment.

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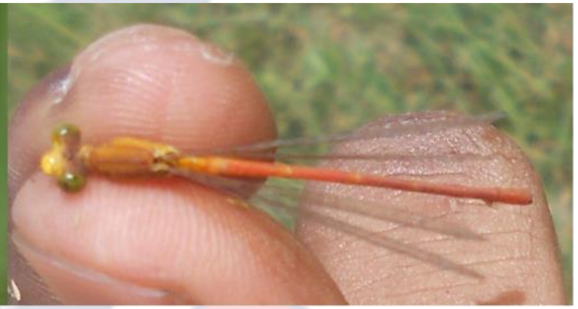
APPENDICES

Appendix A

Images of some dragonflies and damselflies recorded during the study


Bradinopyga strachani


Crocothemis erythrae (F)


Ceriagrion glabrum


Chlorocypha curta


Palpopleura lucia


Deplacodes lefebvrii


Acisoma inflatum

Paragomphus serrulatus

Orthetrum chryosostigma

Phaon camarunensis

Nesciothemis pujoli

Aethiothemis sp

Appendix B

Abundance (N), Diversity (H'), Evenness (J') and Richness (S) of Damselflies

No.	Site	N	H'	S	J'
1	Adisadel Estate	51	1.058	4	0.763
2	Adisadel College	16	0.540	2	0.779
3	Adisadel Village	17	0.882	3	0.802
4	Akotokyir	5	0.673	2	0.971
5	Antem	16	0.685	2	0.989
6	Apewosika	59	0.500	2	0.722
7	Bonkus	5	0.465	3	0.423
8	Duakor	79	0	1	0
9	Efutu	24	0	1	0
10	Esuekyir	6	0.100	3	0.898
11	Fosu Lagoon	35	1.181	4	0.852
12	Kakumdo	16	0.777	3	0.708
13	Kwaprow	17	1.073	3	0.977
14	Science	8	0.662	2	0.954
15	UCC Farm	73	0	1	0
16	UPSHS	25	0	1	0

Abundance (N), Diversity (H'), Evenness (J') and Richness (S) of Dragonflies

No.	Site	N	H'	S	J'
1	Adisadel Estate	71	1.387	6	0.774
2	Adisadel College	49	0.868	5	0.539
3	Adisadel Village	36	0.916	4	0.661
4	Akotokyir	16	1.256	4	0.906
5	Antem	50	1.387	7	0.713
6	Apewosika	17	1.055	6	0.600
7	Bonkus	55	1.634	7	0.840
8	Duakor	42	1.489	6	0.831
9	Efutu	52	0.410	2	0.592
10	Esuekyir	28	0.720	4	0.520
11	Fosu Lagoon	85	1.607	6	0.900
12	Kakumdo	87	1.597	8	0.768
13	Kwaprow	33	1.630	7	0.840
14	Science	81	1.452	6	0.812
15	UCC Farm	44	1.283	4	0.925
16	UPSHS	90	1.376	5	0.855

Appendix C

Presence and Absence of Species in Site Categories

Species	Site Category		
	Least Disturbed	Moderately Disturbed	Highly Disturbed
Damselflies			
Agriocnemis serafica	-	-	7
Allocnemis ellongata	-	3	-
Allocnemis sp	1	-	-
Ceriagrion glabrum	41	113	142
Ceriagrion sp	-	-	28
Chlorocypha curta	-	3	-
Ischnura senegalensis	4	25	64
Phaon camerunensis	17	4	-
Dragonflies			
Acisoma inflatum	9	12	15
Aethiothemis sp	2	8	2
Anax tristis	4	-	-
Brachythemis impartita	-	-	56
Brachythemis lacustris	-	-	3
Brachythemis leucostica	-	-	21
Bradinopyga strachani	1	14	15
Crocothemis erythrae	14	40	43
Diplacodes lefebvrii	1	-	1
Nesciothemis pujoli	17	8	-
Orthetrum austeni	6	15	9
Orthetrum chrysostigma	37	58	19
Pantala flavescens	-	5	-
Palpopleura lucia	25	44	20
Palpolpluera portia	-	8	-
Paragomphus serrulatus	-	2	-
Trithemis arteriosa	84	170	47
Trithemis sp	-	1	

Appendix D

Mean Climatic Variables Recorded at Each Study Site in the Cape Coast Metropolis

Study Site	Mean Temperature (°C)	Mean Light Intensity (klux)	Mean wind speed (mph)	Mean Humidity (%)	Mean water temperature (°C)	Mean pH	Altitude
Adisadel Estate	30.5±3.87	53.1±28.6	1.5±0.51	77±6.91	26.1±0.09	7.2±0.09	8
Adisadel College	31.1±3.05	23.6±3.09	1.1±0	75.8±2.86	28.2±0.18	7.6±0.12	14
Adisadel Village	32.5±2.25	53.2±24.4	1.7±1.76	76.3±2.55	27.1±0.14	7.1±0.04	12
Akotokyir	34.2±8.31	29.5±0.355	0.6±0.58	76.9±13.4	26.3±0.23	7.4±0.01	-6
Antem	31.3±2.6	52.2±12.3	1.1±0	76.3±2.72	28.0±0.23	7.2±0.04	20
Apewosika	33.1±6.77	47.1±32.7	4.0±0.59	82±5.16	27.5±0.13	7.2±0.01	5
Bonkus	37.9±3.51	81.2±8.27	2.1±0.05	64.0±0	30.8±0.13	7.6±0.01	-2
Duakor	33.6±6.44	27.0±14	1.1±0	81.6±4.84	27.9±0.46	7.4±0.01	11
Efutu	34.9±1.79	48.8±15.7	0±0	71.5±3.6	31.7±0.43	7.4±0.01	-38
Esuekyir	34.1±2.19	44.4±17.1	1±0.76	66.3±1.39	30.0±1.51	7.6±0.01	-10
Fosu Lagoon	32.1±4.24	63.9±10.5	1.1±0	74.8±1.67	26.8±0.22	8.5±0.02	-6
Kakumdo	32.7±2.07	41.8±20	1.1±0.04	68.3±4.68	32.8±0.18	7.5±0.01	11
Kwaprow	34.2±7.13	40.5±27.3	1.1±0	80.6±7.45	25.9±0.83	7.6±0.01	-10
Science	35.6±3.24	65.1±19.9	0.4±0.5	66.2±8.66	34.4±1.71	7.8±0.05	8
UCC Farm	32.2±8.78	62.3±26.1	1.1±0	76±7.75	24.0±0.21	7.8±0	-18
UPSHS	36.2±4.55	66.2±12.9	1.07±0.04	72±5.93	28.0±0.22	7.3±0.04	8

Appendix E

Scores of Conditions Showing the Physical Characteristics of Study Sites

Condition	Adisadel Estate	Adisadel Village	Apewosika	Duakor	Adisadel College	Akotokyir	Antem	Bonkus	Fosu
Access to water body	0	0	0	3	3	2	3	2	1
Width of riparian vegetation	1	1	1	1	2	2	1	2	2
Preservation of r. vegetation	0	0	0	1	2	2	1	2	1
Condition of riparian vegetation	0	0	0	0	1	1	1	0	1
Water retention mechanism	1	1	0	0	1	2	1	1	0
Canopy cover	0	0	0	1	2	3	0	2	1
Absence of human occupation	1	0	1	0	2	2	0	1	0
Absence of dom. waste	2	1	1	0	1	1	2	1	1
Building density	1	1	1	1	2	1	2	2	1
Dumpsite	1	1	1	0	3	2	3	2	0
Cropland	3	2	2	1	1	3	0	3	2

Scores of Conditions Showing the Physical Characteristics of Study Sites (Cont.)

Condition	Science Garden	UCC Farm	Efutu	Esuekyir	Kakumdo	Kwaprow	UPSHS
Access to water body	3	3	1	3	3	2	3
Width of riparian veg.	2	1	3	3	2	2	3
Preservation of r. veg.	0	3	2	2	2	2	0
Condition of r. veg	1	0	1	2	1	1	0
Water retention mech.	2	3	1	1	2	3	0
Canopy cover	0	0	1	2	2	1	3
Absence of human occ.	2	3	3	3	3	3	2
Absence of dom. waste	3	3	3	3	3	2	3
Building density	3	3	3	3	3	2	3
Dumpsite	2	3	3	3	3	3	3
Cropland	2	0	3	0	1	3	3

Appendix F

Correlation Matrix showing pearson's correlation between measured environmental variables

	Temp	Light Intensity	Wind speed	Humidity	Water Temperature	pH
Light Intensity	0.58					
Wind speed	-0.01	0.05				
Humidity	-0.51	-0.51	0.02			
Water Temperature	0.13	0.02	-0.3	-0.47		
pH	0.02	0.20	-0.19	-0.14	0.04	
Altitude	-0.13	-0.06	0.31	0.06	0.00	-0.26

Correlation Matrix between characteristics of habitats assessed to determine the habitat integrity of sites

	Condition	1. Access	2.	3.	4.	5	6	7	8	9	10
2	Width of riparian vegetation (RV)	0.23									
3	Preservation of RV	0.35	0.25								
4	Condition of RV	0.32	0.48	0.39							
5	Water retention mechanism	0.25	-0.03	0.49	0.29						
6	Canopy cover	0.39	0.65	0.35	0.17	-0.12					
7	Absence of human occupation	0.32	0.6	0.56	0.41	0.64	0.37				
8	Absence of domestic or industrial waste	0.29	0.51	0.13	0.35	0.44	0.06	0.73			
9	Building density	0.59	0.62	0.34	0.38	0.4	0.26	0.76	0.87		
10	Dumping sites	0.5	0.48	0.49	0.41	0.54	0.32	0.75	0.72	0.8	
11	Cropland	-0.54	0.35	-0.27	-0.27	-0.08	0.19	0.1	-0.03	-0.17	-0.14

Appendix G

Model output of generalised linear model showing the effects of local climatic variables and habitat characteristics on the abundance, diversity and richness of dragonflies and damselflies.

Significant levels: *** (< 0.001); ** (< 0.01); * (<0.05)

Abundance

Model Formula: abundance ~ temperature + wind speed + pH + preservation + condition + water retention mech. + cropland + (1|site/visit).

Effect on Damselfly abundance

Variable	Estimate	Std. Error	Z-value	*p*-value
Intercept	1.266	0.120	10.82	< 2e-16 ***
Temperature	0.109	0.09	1.209	0.227
Wind speed	-0.043	0.128	-0.333	0.739
pH	0.050	0.134	0.374	0.708
Preservation of r. veg.	0.329	0.173	1.901	0.057
Condition of r. veg.	-0.549	0.137	-4.015	5.95e-05 ***
Water retention mech.	-0.245	0.140	-1.752	0.080
Cropland	-0.139	0.124	-1.117	0.264
Over dispersion test: *p*-value = 0.816				

Effect on Dragonfly abundance

Variable	Estimate	Std. Error	Z- value	*p*-value
Intercept	1.298	0.062	21.10	<2e-16 ***
Temperature	0.085	0.063	1.342	0.180
Wind speed	-0.056	0.075	-0.752	0.452
pH	0.148	0.067	2.204	0.028 *
Preservation of r. veg.	-0.056	0.076	-0.735	0.463
Condition of r. veg.	-0.098	0.079	-1.249	0.211
Water retention mech.	-0.049	0.073	-0.669	0.503
Cropland	-0.066	0.070	-0.942	0.346
Over dispersion test: *p*-value = 0.96				

Richness

Model Formula: richness ~ temperature + wind speed + pH + preservation + condition + water retention mech. + cropland + (1|site) + (1|visit)

Effect on Damselfly Richness

Variable	Estimate	Std. Error	t- value	*p*-value
Intercept	2.38	$8.83e^{-02}$	26.998	
Temperature	$-1.14e^{-15}$	$5.77e^{-09}$	0	1
Wind speed	$3.63e^{-15}$	$1.17e^{-08}$	0	1
pH	$1.60e^{-15}$	$4.37e^{-08}$	0	1
Preservation of r. veg.	-0.413	0.181	-2.288	0.022*
Condition of r. veg.	-0.161	0.092	-1.751	0.080
Water retention mech.	0.111	0.136	0.818	0.413
Cropland	-0.016	0.105	-0.152	0.880

Effect on Dragonfly Richness

Variable	Estimate	Std. Error	t- value	*p*-value
Intercept	3.962	0.416	9.534	
Temperature	0.376	0.112	3.361	$7.76e^{-4}$ ***
Wind speed	-0.137	0.106	-1.298	0.194
pH	0.391	0.274	1.43	0.153
Preservation of r. veg.	-0.504	0.350	-1.439	0.150
Condition of r. veg.	-0.159	0.286	-0.555	0.579
Water retention mech.	0.415	0.325	1.279	0.200
Cropland	0.041	0.283	0.143	0.886

Diversity

Model formula: diversity ~ temperature + windspeed + pH + preservation + condition + water retention mechanism + cropland + (1 | site) + (1 | visit)

Effect on Damselfly Diversity

Variable	Estimate	Std. Error	t value	Pr(>Chisq)
(Intercept)	0.638	0.044	14.257	
Temperature	$-2.04e^{-16}$	$2.35e^{-09}$	0	1
Wind speed	$2.83e^{-15}$	$4.76e^{-09}$	0	1
pH	$1.91e^{-14}$	$1.78e^{-08}$	0	0.99
Preservation of r. veg.	-0.326	0.087	-3.746	$1.80e^{-4}$ ***
Condition of r. veg.	0.076	0.043	1.765	0.08
Water retention mech.	0.165	0.059	2.787	$5.32e^{-3}$ **
Cropland	0.049	0.047	1.047	0.30

Effect on Dragonfly Diversity

Variable	Estimate	Std. Error	t value	Pr(>Chisq)
Intercept	1.34	0.018	74.902	
Temperature	$8.39e^{-16}$	$2.74e^{-09}$	0	0.99
Wind speed	$-8.46e^{-15}$	$4.44e^{-09}$	0	0.99
pH	$-3.04e^{-14}$	$2.18e^{-08}$	0	0.99
Preservation of r. veg.	-0.086	0.022	-3.832	$1.27e^{-04}$ ***
Condition of r. veg.	-0.011	0.018	-6.289	$3.203e^{-10}$ ***
Water retention mech.	0.016	0.021	7.507	$6.046e^{-14}$ ***
Cropland	0.038	0.019	2.056	0.040 *