

Diversity and Ecology of Odonates in Coimbatore District

Thesis

submitted to the Bharathiar University
in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in
Zoology

by

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August 2017

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This is to certify that the thesis entitled “**Diversity and Ecology of Odonates in Coimbatore district**” submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Zoology is a record of original research work done by **Ms. Suhirtha Muhil. M** during the period September 2012 - August 2017 of her study in the Department of Zoology at Sálim Ali Centre for Ornithology and Natural History under my supervision and guidance and the thesis has not formed the basis for the award of any Degree / Diploma / Associateship / Fellowship or other similar title to any candidate of any University.

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CHAPTER 1

INTRODUCTION

The global biological diversity is to be treated as a wealth considering its potential role in ecosystem sustenance and management. The declining status and vulnerability of biological diversity to various human-induced problems, compels us to index and preserve species and their habitats as a continuous and crucial process. Exploding human population, degrading environment and loss of habitats are three major reasons for the irreversible loss of biological diversity especially in the tropics (Wilson, 1988). To understand the causes behind the ecological and evolutionary processes responsible for the rich biodiversity and also the ecosystem service biodiversity provides, it is very essential to know how many species inhabit this earth (May, 2011). There are presently 1.9 million catalogued species in the world of which nearly one million are insects (Chapman, 2009), while the estimated number of global species by taxonomists is between three and 100 million species (May, 2010). This estimation of biodiversity based on taxonomic patterns varies from the estimates based on macroecological patterns and diversity ratios. Erwin (1982) estimated 30 million species of Arthropods, based on the host specificity of guilds in beetle samples and subsequent hierarchical ratio extrapolations. There was much debate on this estimate and until the early 1990s, global species richness was thought to be two to three times the number of described species (*i.e.* 2–3 million species) (Stork, 1997). The modified version of Erwin's estimate of tropical arthropod species richness was estimated at 4.8 million species (minimum 2.4 million species, and maximum 10.2 million species) (Ødegaard, 2000). Presently, the estimation of total number of taxonomic groups of all domains of life predicts 8.7 million eukaryotic species globally, of which, 2.2 million are marine (Mora *et al.* 2011).

Among the 29 orders of insect species, Coleoptera stands first in the status of insect species described (3,50,000 insects; 36.2%) followed by Lepidoptera (1,75,000 insects; 18.1%) and Diptera (1,60,000 insects; 16.6%) (Zhang, 2011). The number of species described under Odonata is around 6,000 (Jackson, 2014), which constitute only 0.6 per cent of the total insect species described. The recent analysis by the International

Union for Conservation of Nature (IUCN) included 993 species in the threatened list of insects. Of these, Odonates top the list with 266 species based on the access to 2791 species by IUCN (Jackson, 2014).

Dragonflies are among the most ancient insects, which date back to the Permian age (Grimaldi and Engel, 2005). At present the Order Odonata is subdivided into the Suborder Zygoptera (equal wings); Anisoptera (subequal wings) and Anisozygoptera. Anisozygoptera has only four Asiatic species. In addition to the 6,000 species of Odonates already reported in the world. Additionally, 150 new species have been reported since 2011 (Dijkstra *et al.* 2013; Dijkstra *et al.* 2015). Of the described Odonate species of Odonates (30 families, 653 genera), 2,941 belong to the Suborder Zygoptera (18 families, 308 genera), 3,011 species to the Anisoptera (11 families, 344 genera), and two species in Epiophlebia genus of Anisozygoptera (Dijkstra *et al.* 2013).

Studies on Odonates were mainly focused on systematics until 1917, when '*The Biology of Dragonflies*' was published by Tillyard, detailing the morphology, anatomy, taxonomy and natural history of Odonates (Khelifa *et al.* 2017). Later the seminal works by Corbet (1962, 1980, 1999) updated the details of biology, ecology and behavior of Odonates.

Odonates are increasingly used in both fundamental and applied research with relative ease because of their broad array of ecological behaviours and ability as bioindicators in assessing aquatic habitats. For instance, Odonates remain as model organisms to test important theoretical questions related to sexual selection, complex life cycle, the evolution of flight and community ecology (Cordoba-Aguilar, 2008). They are also used as indicators of environmental health and conservation management (Corbet, 1999). The sensitivity of these insects to habitat structures (shade, shoreline conditions, substrata type and flow conditions) and their amphibious habits make dragonflies well suited for evaluating environmental change both above and below the water surface (Osborn, 2005; Stewart and Samways, 1998; Remsburg *et al.* 2009). Odonates have been proved to be excellent indicators in the assessment of aquatic systems (Schindler *et al.* 2003). They have been used to monitor and prioritise conservation and management

efforts on aquatic bodies (Simaika and Samways, 2012). Range extension studies of Odonates by latitude suggest that they could provide information on climate change (De Knijf and Anselin, 2010; Bush *et al.* 2012). Thus, a variety of factors make Odonates an ideal taxon for investigating the impacts of environmental degradation and climate change. These include 1) limitations of distribution by temperature, 2) seasonal regulation in Odonate activity, 3) high local abundances in some species, making field work involving ecological sampling not only feasible but relatively straightforward, 4) a long history of scientific research into both their ecology and behavior and 5) extensive amateur recording, resulting in an exhaustive historical databases of sightings.

Diversity and distribution of Odonates have been well documented in the temperate region, yet richness is known to be higher in the tropics (Kalkman *et al.* 2008). Not much is known about their potential richness and habitat interactions in the tropics (McPeck, 2008). Ecological studies of Odonate in the Indian scenario are limited (Subramanian *et al.* 2008; Das *et al.* 2013; Koparde *et al.* 2015). Hence to address these issues, the present study aims to assess the Odonate diversity, distribution and the factors influencing the distribution of Odonates across a wide range of aquatic habitats within Coimbatore district with the following specific objectives:

1. to survey and document Odonates in Coimbatore district.
2. to examine the spatio-temporal variability and diversity of Odonate communities in different aquatic ecosystems of Coimbatore district.
3. to examine the factors influencing Odonate diversity and composition among different aquatic ecosystems in Coimbatore district.

1.1.Thesis Organisation

The thesis has seven chapters, with three technical chapters addressing the above mentioned three objectives. The first introductory chapter covers present status of Odonates, their significance as bioindicatros and the objectives of the present study. The second chapter provides literature review about the taxonomy, biology and distribution of Odonates in freshwater ecosystems. The third chapter is to give a detailed account on the study area, study design and field methods followed. In the fourth chapter, the

community composition of Odonates recorded in the study area is presented and discussed based on the primary data collected and the available secondary data from earlier studies. This chapter also discusses the endemicity of Odonates in the region. The fifth chapter is on spatial and temporal diversity of Odonates in the study area and how spatial and seasonal variation influence Odonate diversity and composition. The factors which influence the Odonate assemblages have been analysed in the sixth chapter using multivariate analyses. The last chapter summarises the findings of the present investigation with conclusion and furtherance of the studies on Odonates.

CHAPTER 2

REVIEW OF LITERATURE

Odonates are considered as first winged insects to evolve over 300 million years ago. The first known fossils of dragonfly like insects were from the Upper Carboniferous Era (Hovmoller, 2006). The insect order Odonata (which means “toothed one” in Greek) consists of the dragonflies and damselflies. There are more than 6,000 known species of Odonates in the world (Dijkstra *et al.* 2013). The Odonates possess incredible vision and have the capacity of preying and mating in the mid-air. They are widely distributed throughout the world except the poles (Corbet, 1980). Khelifa *et al.* (2017) divided the history of Odonatology into four eras: Selys era (systematics), Tillyard era (biology), Corbet era (behaviour and ecology) and the new era (phylogenetics and climate change). The following section has a comprehensive review on the components namely., taxonomy and classification, biology, distribution and ecological role of Odonates.

2.1. Taxonomy and Classification

Taxonomy is fitting biological organisms into groups based on shared characteristics. Historically taxonomical grouping was carried out exploiting morphological characteristics and the Odonates were also grouped at different levels. The first attempt to group these insects was by Linnaeus (1758) who described only 18 species and placed them in the genus *Libellula*. Fabricius made the list of 69 species was the first to give to dragonflies a separate ordinal status with the name ‘Odonata’ in 1793 (Khelifa *et al.* 2017). The classification of Odonates based on wing venation was initiated by Baron Michel Edmond de Selys-Longchamps described 700 species and established 134 valid genera (Wasscher and Dumont 2013). The grouping of Odonates based on morphological characteristics was attempted by Fraser (1957), Hennig (1969), Hennig *et al.* 1981, Pfau (1991), Trueman (1996), Bechly (2002). The order Odonata has been divided into two suborders *viz.*, the Anisoptera (dragonflies) and Zygoptera (damselflies). A third suborder, Anisozygoptera, has currently been included under Anisoptera, with a new name Epiprocta (Kalkman *et al.* 2008). Though many morphological characteristics have been involved in classifying the Odonates, no robust conclusion could have been established regarding the relationships of the Odonates. This led to the utility of molecular characteristics at

DNA level to resolve the relationship among the Odonates with more accuracy. Dijkstra *et al.* (2013) updated the classification of Odonates based on 5952 extant species in 652 genera described up to 2010 and cautioned the usage of wing venation as sole morphological characteristic in classifying Odonates. Hovmoller (2006) involved two molecular markers from the mitochondrial DNA *viz.*, 16S ribosomal DNA and cytochrome oxidase II (COII), a protein coding sequence to resolve the taxonomic issues in dragonfly systematics. Ware *et al.* (2007) carried out the molecular phylogenetic analysis of Libelluloidea, a family with more number species and suggested that along with molecular data combining the biogeographical information would make the classification more accurate. Dijkstra *et al.* (2014) made a comprehensive molecular phylogenetic analysis based on mitochondrial (16S, COI) and nuclear (28S) data of 59% of the 310 genera of Zygoptera and concluded that many long-established families lack strong morphological uniqueness and involving wing venation for classifying damselflies was incongruent with molecular results. Subsequently, Carle *et al.* (2015) established a phylogeny of Anisoptera employing 510 representatives of 184 genera (of ca. 380) in 11 families based on nuclear and mitochondrial ribosomal RNA, the mitochondrial protein coding genes COI and COII, nuclear protein coding genes EF-1 α and Histone H3 and reported deviations in the established classification of dragonflies. Bybee *et al.* (2016) proposed to exploit Odonates as a bridge between evolutionary genomics and ecology because of their phylogenetic position, extensive phenotypic and ecological diversity and complex life cycle so that a high resolution classification of Odonates can be established.

2.2. Biology

The Odonates are the most ancient forms of winged insects, existing since the Permian age (Grimaldi and Engel, 2005) and are amphibiotic, the larval phase is completely aquatic and adult phase is terrestrial. Odonates are carnivores in the insect world; both adult and larval forms are predatory in nature. The dragonflies are considered as special insects because of the following characteristics: mouthpart that allows the Odonates to be fierce predators, rectal gills that enable dragonfly nymphs to respire in water, direct flight muscles to each wing making all the four wings to move independently, secondary genitalia and unique territoriality of males. Tillyard (1917) Corbet (1962) and Corbet (1980) documented various aspects related to the biology of the Odonata with Corbet (1980) detailing the following components *viz.*, 1)

habitat selection and oviposition, 2) the egg stage, 3) the larval stage, 4) growth stage, 5) adults' general feeding and reproductive behaviour, and 6) dispersal.

Habitat selection must be developed in both sexes, being directed towards mating in the males, and towards mating and oviposition in the females. Oviposition site selection is crucial in the life history of Odonates since females must find a suitable habitat to enhance larval survival and development. The Odonates habitat selection for oviposition is influenced by darkness or brightness and the type of vegetation in waterbodies. Bernath *et al.* (2002) reported that dragonflies identify dark and bright waterbodies based on the degree of polarization of reflected light as a possible clue for habitat selection. Guillermo-Ferreira and Del-Claro (2011) reported that different types of vegetation influence site selection of the damselfly *Oxyagrion microstigma* in a Neotropical Savanna pond. The density of males was found to be more with higher densities of the *Eleocharis* sp. (Cyperaceae) but with lower densities of the *Pontederia parviflora* (Pontederiaceae). The egg laying habit of Odonates may be endophytic or exophytic and it varies from species to species. Matushkina and Lambret (2011) studied the ovipositor morphology and egg laying behaviour of *Lestes macrostigma*, it preferred egg laying in *Bolboschoneus maritimus*. Oviposition is carried out in stems of *B. maritimus* and *Juncus maritimus*. Larvae of Odonates generally occupy aquatic habitats. But the larvae of some species occupy the leaf bases or water containing tree holes. The site selection by larvae in aquatic habitats is primarily for the resource partitioning (Corbet, 1980). The larvae are known to prey on mosquito larvae in water and some larvae even prey on small fishes. During the adult stage of Odonates, understanding the intraspecific colour variation, colour vision, and territoriality are considered as some special features.

Intraspecific colour variation in Odonates is attributed to three components *viz.*, polychromatism, ageing and temperature induced colour change. Polychromatism is generally found among Zygoptera and is under the genetic control whereas temperature induced colour change in Odonates is reversible. Colour variations are used to communicate their sexual state and believed to be evolved through sexual selection (Shuster and Wade 2003; Arnqvist and Rowe, 2005). Hammers and van Gossam (2008) conducted a study on these colour polymorphisms in mixed populations of the damselfly *Ischnura elegans*. Mature males of *I. elegans* are colour monomorphic, whereas mature females occur as one of three discrete colour morphs:

an androchrome (male mimic), which is similar to males with respect to body colouration and melanin body patterning, and two gynochromes (*infuscans* and *rufescens obsoleta*), which do not resemble males in body colouration. This colour polymorphism is genetically inherited and is controlled by three alleles at a single autosomal locus with sex-limited expression and a dominance hierarchy with androchrome > infuscans > rufescens-obsoleta (Sanchez-Guillen *et al.* 2005). Males and females also show ontogenetic changes in body colour, with immature and mature individuals differing in colour (Sanchez-Guillen *et al.* 2005). Huang and Reinhard (2012) reported change in colour of blue andromorphs of Australian damselfly species *Ischnura heterosticta* into green-grey gynomorph when they are ready to mate. This male-mimic to gynomorph situation happens in 24 hours and remains permanent. Another advantage of the male-mimicness in females helps them to escape from the sexual harassment by males. Like male-mimics, female mimics of males were also observed in *Mnais costalis* and these female mimics are not territorial but remain as sneakers (Tsubaki, 2003).

Humans have tri-chromatic vision and see colours as a combination of red, blue and green and this is because of three different light sensitive proteins called opsins. In Odonata, a study conducted by involving 12 dragonfly species representing 11 families revealed presence of 15-33 different visual opsin genes indicating better colour discrimination capacity than humans (Futahashi *et al.* 2015). Multiplied opsin genes may play substantial roles in ecological adaptation of dragonflies *via* finely tuned visual systems for better thriving. Futahashi (2016) published a detailed review on the genetic basis of colour polymorphisms, colour vision and diversity of opsin genes and colouration mechanism in dragonflies.

Males of many species of dragonflies are territorial in their habitats and compete with other males for their food and females. The preliminary concept on the evolution of Odonate territoriality was proposed by Johnson (1962a, 1962b, 1962c). According to Corbet (1962), this aggressive behaviour occurs above water and has the possible functions of: maintenance of food supply, initiation of dispersal, and prevention of interference with mating and oviposition. Johnson (1964) defines Odonate territorial behaviour as a species-specific interaction between males at the breeding site, especially noticeable when females are present. Sexually dimorphic colour patterns common in Odonate species function as sex recognition devices which

initiate sex drive and aggressive behaviour, while territoriality functions primarily to prevent over-competition for females at the breeding site (Johnson, 1962a; 1962b; 1962c). Plaistow and Tsubaki (2000) reported colour polymorphism in males of the damselfly *Mnais costalis*.

Thermoregulation in body temperature is one of the biological properties of Odonates and is related to body size and behaviour and is more pronounced in temperate than tropical species (May, 1976). Cooling-off and warming up in dragonflies are common activities. Dragonflies reduce their body temperature by keeping their body in obelisk posture less exposed to sunlight. When the temperature is low dragonflies undergo wing-whirring to get warmed-up. Wing pigmentation is expected to play an adaptive role of dragonflies for thermoregulation. Corbet and May (2008) concluded that there are clear-cut differences between the thermoregulatory strategies in fliers and perchers of Odonates and within each category a continuum exists such that the capacity to heat the body by irradiation (*i.e.* exothermically) or by metabolic heat production (endothermy) increases with body size.

2.3. Distribution of Odonates

2.3.1. World level

The Global Species Database of Odonata built over a period of twenty years (van Tol, 2017) remains as a source of all names of extant species of dragonflies and damselflies of the world. As per the database, there are 5912 living species under the order Odonata. Kalkman, *et al.* (2008) enumerated the number of genera and species per family, number of endemic species and percentage of endemism for each bio-geographical regions *viz.*, Afro-tropical (Ethiopia, South Africa and Madagascar), Oriental (Taiwan, Borneo, Hainan and Sri Lanka), Palaeartic (Northwest Africa and Japan), Neotropical (Cuba, Costa Rica and Venezuela), Australasian (Sulawesi and New Zealand) and Pacific (Hawaii and New Caledonia). The Oriental region along with the Neotropical is the most species rich regions. The families Chlorogomphidae and Euphidae are completely restricted to the Oriental region.

The percentage of endemism for each of the bio-geographical regions was reported by Kalkman, *et al.* (2008). The percentage of endemism was found to be high in islands: Madagascar (77%), Hawaii (72%), New Zealand (59%), Borneo

(46%), Sri Lanka (46%), Sulawesi (44%), New Caledonia (40%) and Japan (34%). Unfortunately the enumeration of global diversity of Odonata did not include the data from Indian subcontinent. The Odonata distribution is widespread and abundant on all continents except Antarctica and tropical forests remain as centres of species richness (Kalkman *et al.* 2008). Odonate species richness is clustered in the Neotropical and Indo-Malayan realms, which contain almost 60% of the world's Odonata diversity (Clausnitzer *et al.* 2009). Globally, the members of the Libellulidae family were found to be widespread and speciose and adaptable to a wide range of aquatic bodies (Suhling *et al.* 2009; Ware *et al.* 2012)

2.3.2. National level

The major contribution on Indian Odonata was from Fraser (1918-1936) in British India. A total of 537 species and subspecies under Odonata were reported by Fraser (1933, 1934 and 1936) in his Fauna of British India including Ceylon and Burma volumes. After Independence, the Zoological Survey of India started its collection of fauna from different parts of India and those collections formed basis for the publications on Odonata fauna of Meghalaya (Lahiri, 1987), Orissa (Srivastava and Das, 1987), West Bengal (Srivastava and Sinha, 1993) and Bihar (Prasad and Varshney, 1988). However, these publications had less information on geographical distribution and ecology of Odonates of the above states (Mitra, 2002). Mitra (2002) made an exhaustive study on the geographical distribution of Odonata of Eastern India and reported 132 species under 38 genera of Zygoptera, one species from Anisozygoptera and 256 species under 73 genera of Anisoptera. Within the Indian sub-region the greatest number of species and endemics in Odonata occur in tropical forests. Richest are the tropical and subtropical forests in south of Himalayas, including Sikkim, North Bengal and the Khasi Hills, with other centres of diversity in the Western Ghats and Nilgiris and the wet south-western and central part of Sri Lanka (Lahiri, 1989; Bedjanic, 2004). Cataloguing of Odonates of Peninsular India, Central India and Eastern Himalayas were made by Subramanian (2005), Andrew *et al.* (2008), Mitra *et al.* (2011), respectively.

2.3.3. State level

A total of 135 species of Odonates have been listed in Tamil Nadu (Emiliyamma, 2009). Of this, 96 species were recorded by Fraser (1931, 1933, 1934

and 1936), which were primarily from the western part of the state, of the Nilgiris and Coimbatore district. Another 39 species has been added to the state from various studies (Arunkumar, 1989; Palot and Soniya, 2000; Asaithambi and Manickavasagam, 2002; Emiliyamma and Radhakrishnan, 2003). Thirty nine species of Western Ghat endemics have been recorded from the state (Subramanian, 2006). High endemism is exhibited by the Gomphidae, Corduliidae, Platystictidae and Protoneuridae families (Emiliyamma, 2009).

The western section of the State comprising of the Bhavani and Moyyar river valley are among the highly species rich Odonate zones in the Western Ghats (Subramanian *et al.* 2011). Similarly, highly species rich (85-111 species per basin) zones are found to extend along the southern Western Ghats along the Cauvery (Amaravati river), Vaigai and Periyar rivers (Subramanian *et al.* 2011)

2.3.4. District level

The first records of Odonates in the Coimbatore district were made by Fraser (1924, 1931, 1933, 1934, 1936) during which he recorded 48 species. Since then several studies have added to the region's species list of 69 species of Odonates (Ayyar and Ayyar, 1933; Abraham, 1959; Gunathilagaraj *et al.* 1999; Arulprakash and Gunathilagaraj, 2009; Arulprakash and Gunathilagaraj, 2010a; Arulprakash and Gunathilagaraj, 2010b; Karthika and Krishnaveni, 2014). Much of the works in Odonates have been confined to checklisting and life history of only very few species are known. There are some habitat assessment studies in India (Subramanian *et al.* 2008; Koparde *et al.* 2015). Given the lacunae in Odonate studies in the region, it is essential to explore the wide habitat specificities of species and assess the conditions of aquatic habitats which are under rapid pressure.

2.3.5. Factors influencing distribution of Odonates

Odonates are known to be influenced by a wide variety of environmental factors. Life history characteristics such as phenology, synchrony and voltinism influence the population structure of a region (Wissinger 1988). Odonates are positively correlated with vegetation (Buchwald, 1992; Remsberg *et al.* 2008; Elo *et al.* 2015). In pristine sites, with little or no disturbance, water quality tends to be the most influencing factor in affecting Odonate distribution (Kietzka *et al.* 2016).

Diversity of tropical Odonates is at least partly explained by the high diversity of aquatic habitats in tropical forests (Orr, 2006), especially in montane areas (Oppel, 2005)

Mobility of adult Odonates aids in foraging, mating and maintain a territory. Generalist species tend to be highly mobile and this aids in their distribution across wide habitats (McCauley, 2008). It is established that sites with high larval density also have high density of adult Odonates and indicate the importance of oviposition site selection by adults (Remsburg, 2011). Odonate species vary on selecting sites for oviposition based on area of open water and vegetation (Corbet, 1962). Larval growth varies depending on the permanence of water, i.e. seasonal waterbodies have rapidly emerging adult forms and permanent water bodies have slowly developing larvae. Similarly, the presence of predators influences delayed larval development (McPeck, 2008), when compared to fishless waterbodies (Stoks *et al.* 2005). In fishless ponds, snails are predated by Odonates and their abundance is negatively influenced by larval Odonate in the ponds (Turner and Chislock, 2007). Fish and dragonfly larvae are highly susceptible to pond drying (Wellborn *et al.* 1996). Temporary water specialists (*Pantala* and *Sympetrum fonscolombii*) were found to be more active compared to permanent water specialists (*Trithemis* and *Crocothemis*) (Suhling *et al.* 2005). Activity is the most important factor in shaping the species transition across a permanent and temporary water regime. Greater activities imply greater growth rate. *Pantala flavescens* has a fast developing period of 40 days, with as many as 2 to 3 generations a year (Johansson and Suhling *et al.* 2004).

Rice field Odonate do not thrive, from previous year diapause because the fields are dried out and ploughed before the next sowing. Hence adults have to colonise the rice field. Difference in stream Odonate communities was observed in rainforest streams and more open streams (O'Neill and Paulson, 2001). There is a strong difference in the Odonate composition based on running water and stagnant sites (Suhling, 2001)

2.3.6. Seasonality and Migration

The families Coenagrionidae and Libellulidae have the highest migratory capacity and also the widest in distribution. Certain migratory species such as *Pantala flavescens* have large asymmetric size advantage in larval development over other

resident species. They oviposit earlier and are larger in each instant compared to the larval stages of other residents. They are most abundant by mid and late summers when most of the residents are much smaller (Wissinger, 1988). Migration of this species is a yearly phenomenon in India. Swarms of this species are seen in September and this population is known to migrate to East Africa (Anderson, 2009).

2.4. Odonata as Bioindicators

Adult Odonates are known to be important indicators in assessing terrestrial habitats (Dolný *et al.* 2012; Wildermuth, 2010). Many of the Odonate species are habitat specialist. Forest specialists in close forested canopy were affected by the modification in forest landscape in Papua New Guinea. Similarly, species associated with temporary waters with microhabitats in the forest interior were found to be intolerant to deforestation (Opper, 2005). Wetlands are also known to be ecologically important zones in supporting Odonates (Reece, 2000). Invasive plants are known to affect many Red-listed Odonates (Samways and Taylor, 2004). Landscape modifications in forest have shown to change Odonate composition (Samways and Sharratt, 2009). The larvae of Odonates are sensitive to organic pollution and thus serve as a good bio-indicator (Kiritani, 2000).

Long term monitoring of Odonates has revealed that Odonates can also serve as indicators of climate change. Temperate latitudes have led to the widespread dispersion of many partivoltine species and restriction of univoltine species to a narrow distribution (Flenner and Sahlen, 2008). Rise in temperature due to climate change have known to affect development in seasonally dependent univoltine species (Flenner *et al.* 2010). In the Mediterranean area, De Knijf and Anselin (2010) have noted the range extension of many southern species. Odonates in the Southern region of Britain have known to be increasing their range size northwards, which could be attributed to climate change and improved habitat quality in the northern region. The shifts in range margins are directly linked to climatic suitability (Hickling *et al.* 2005). In the Netherlands, change in spring temperature has led to the advancement in phenology of dragonflies (Dingemans and Kalkman, 2008). The changing climate and the biodiversity crisis to the Odonata community need an immediate conservation strategy by forming ecological network covering potential habitats of Odonata so that Odonates can be better exploited for ecological and evolutionary research in biology.

CHAPTER 3

STUDY AREA AND METHODS

3.1. STUDY AREA

3.1.1. Location and extent

The present study was conducted in selected aquatic habitats of Coimbatore district. The district of Coimbatore lies in the western part of the state of Tamil Nadu. The district lies between 10° 10' and 11° 30' N and 76° 40' and 77° 30' E, encompassing an area of 4,723 sq.km. Nearly one fourth of the region (1,052 sq.km) is covered by reserve forests.

3.1.2. Physiography

Coimbatore district lies in a raised upland plateau region of Tamil Nadu, which gently tapers into the plains in the East. The district is bounded by the Western Ghats in the north, south and west. Part of the district falls under the leeward side of the Western Ghats.

This continuous mountain chain runs all through the western coast of peninsular India, from the state of Gujarat to the southernmost tip of the country. There is however one major gap, the Palghat gap, a 40 km undulating plain which intercepts this mountain range in east-west direction, connecting the west coast and plains of Tamil Nadu. Studies have shown that Palghat gap acts as a geographical barrier to many of the montane species, high genetic differences in species owing to the geographical gap (Robin *et al.* 2010; Deshpande *et al.* 2001; Bahulikar *et al.* 2004; Vidya *et al.* 2005).

The hills of Nilgiris are located North of Coimbatore district which form the most elevated section of the Western Ghats. To the South of the district beyond the Palghat gap lies the Anaimalai hill range, a high rising section of the Western Ghats which continues till the southern tip of the country. To the west of the district lie the hills comprising of Siruvani, Anaikatty and Walayar forests. It is a continuous section from the Nilgiris in the North. These hills also run in east-west direction forming three valleys and floodplains for the Noyyal and Bhavani River.

3.1.3. Geology and Soils

The Coimbatore district is known to be made up of Dharwar Craton age, followed by charnokites, peninsular gneiss and youngest intrusives. The most widespread rock type is the peninsular gneiss (Soil Survey and Land Use Organisation, 1972).

Twenty six soil series have been established in Coimbatore district and are grouped into: Red soils (calcareous and non-calcareous), red colluvial soils (calcareous and non calcareous), black soil, brown soil (calcareous), alluvial soils (calcareous and non calcareous) and mixed soils. Major areas have loamy soil, clayey soil, red soil and calcareous black cotton soil as the predominant soil type. The soils of Coimbatore are enriched with organic matter from the hill ranges.

3.1.4. Vegetation

Coimbatore forest division is covered with Southern tropical dry deciduous forest (47%) and Southern tropical thorn forest (29%). Tropical semi evergreen (8%) and wet evergreen forests (2%) are found in hill tops (Champion and Seth, 1968). Only 23 % of the district is under irrigated agriculture (87% by dug wells and 5% by tube wells) (Subburaj, 2008).

3.1.5. Rainfall and climate

The region receives rainfall from both southwest monsoon (June-September) and northeast monsoon (October-November). However, the distribution of rainfall markedly varies throughout the district. Predominantly the district is considered to be exceptionally dry, receiving scanty and ill-distributed rainfall (Soil Survey and Land Use Organisation, 1972).

The Palghat gap, the Anamalai hills, the higher reaches of the Coimbatore hills and the Nilgiris receive heavy rainfall from the southwest monsoon (>800mm) (Rathod and Aruchamy, 2010; Arun and Vijayan, 2004). The rest of the district receives scanty rainfall during the southwest monsoon. Most of the streams, rivers and tanks in the leeward side of the Western Ghats are filled due to rain in the upper sections of the hills. Most parts of the plains in the district experience strong dry westerly wind and occasional rain during the southwest monsoon.

Southwest monsoon has been known to be erratic with frequent droughts in this part of the country (Soil Survey and Land Use Organisation, 1972). The district receives most of its rainfall from the northeast monsoon from October to November (600-800mm) (Rathod and Aruchamy, 2010).

Summer lasts from April to May (mean maximum temperature 35°C and minimum temperature 23°C). Occasional summer showers are frequent in some parts of the district. Southwest monsoon lasts from June to September; similarly the northeast monsoon occurs during the months of October and November. Winter in the region is mainly from December to January (mean maximum temperature 29°C) and a minimum temperature of (mean 19°C). February and March remain dry and warm and prelude the summer (indiawaterportal.org) (Figure 3.1).

3.1.6. Drainage

The major rivers that drain in this region are the Bhavani, Noyyal and Aliyar River. Of these, Bhavani and Noyyal rivers originate from the Western Ghats and North of Palaghat Gap and both these rivers drain into River Kaveri in the East. The Aliyar River originates from the Western Ghats, but South of Western Ghats, this river drains into River Bharathapuzha and flows west towards the Arabian Sea.

3.1.6.1. Noyyal River

The Noyyal is a seasonal river. The western section of the river receives rainfall mostly from the Southwest monsoon and the eastern section of the river from the Northeast monsoon. It originates from major forest streams in the Siruvani and Booluvampatti ranges. It holds a series of irrigational tanks along its flood plain. These tanks were built from 900 AD onwards, to hold the over flowing Noyyal water during the monsoon and acts as percolation structures to recharge ground water (Srinivasan *et al.* 2014).

3.1.6.2. Aliyar River

The Aliyar or Ambarampalayam River originates in the Anamallai hills of the Western Ghats and flows 22km before entering the plains. Water is released from the Aliyar catchment, through two canals, *viz.*, the Vettaikaran Pudur canal and Pollachi

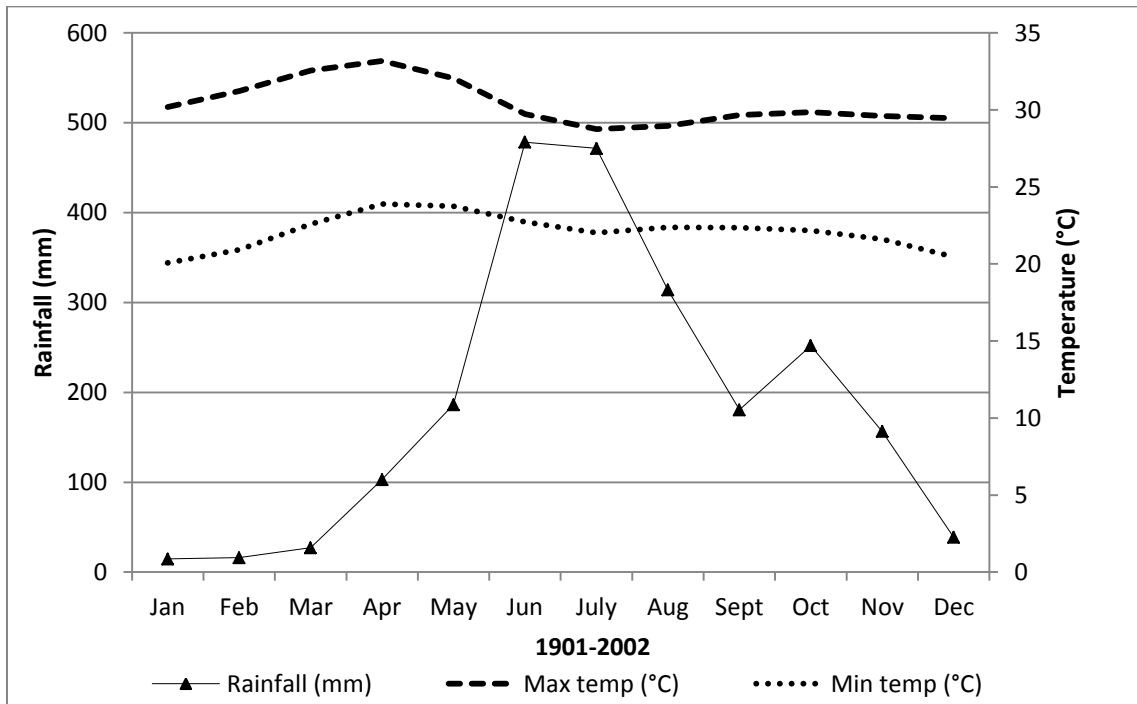


Figure 3.1. Monthly mean rainfall, maximum and minimum temperature of Coimbatore district over hundred years. (source: www.indiawaterportal.org)

canal. The river flows through the adjacent villages next to Pollachi and reaches Kerala at Chitur Taluk. Later, with other tributaries it drains into the Bharathapuzha.

3.1.6.3. The Bhavani River

The Bhavani River an important tributary for the Cauvery River originates from the north-western corner of Nilgiris in the Upper Bhavani section. It flows through the Attapady plateau and enters the plains near Mettupalayam town. Kallar and Moyyar are other tributaries of the Bhavani River. Bhavani river eventually joins with the Cauvery River near Erode.

3.2. METHODS

3.2.1. Study design

Reconnaissance survey was conducted in various aquatic bodies in Coimbatore district from September 2012 to July 2013. During this period, study locations for the intensive study were fixed (Figure 3.2). The study locations were selected, in such a way that they encompassed different aquatic habitats and were also spatially distant. A total of 24 locations was selected for the study; of these 14 sites fall in the drainage basins of the Noyyal River, 6 sites in the Bhavani River and 4 in the Aliyar River (Table 3.1). The sites were grouped based on their aquatic habitats: the forest streams, rivers, permanent tanks, seasonal tanks and paddy fields (Plate 3.1).

Forest stream: Five hill streams located near forest reserves were selected for the study. Two forest streams were located in the Noyyal river basin near Siruvani forest and two forest streams were located in the Anaikatty hills, which drains into the Bhavani River in Attapady plateau. One forest stream from the Kallar valley was also selected, this stream also drains into Bhavani river's tributary channel Kallar.

River: There are totally nine study sites in this classification. Four sites along the Aliyar River were fixed as intensive study locations. All of the sites were downstream of the catchment area and all sites were situated in an agrarian landscape in the Palghat gap. Along the Bhavani River, three river sites were selected. One site was in the upstream of the catchment area (B_CP) and two of them were in downstream (B_VIL, B_BKL) of the catchment area. Two river sites along the Noyyal River were selected and water flow in these river areas was seasonal.

Table 3.1 Intensive study locations

Locations	Habitat	Altitude (m)	Co-ordinates
Bhavani river basin			
B_KALR	FS	379	N 11 ⁰ 20'15.0" E 76 ⁰ 52'54.1"
B_BKL	R	315	N 11 ⁰ 17'37.6" E 76 ⁰ 53'30.4"
B_VIL	R	327	N 11 ⁰ 16'55.4" E 76 ⁰ 51'54.9"
B_CP	R	486	N 11 ⁰ 09'23.2" E 76 ⁰ 55'38.9"
B_SAC	FS	626	N 11 ⁰ 05'45.48" E 76 ⁰ 46'46.32"
B_KOND	FS	629	N 11 ⁰ 06'27.41" E 76 ⁰ 47'37.27"
Noyyal river basin			
N_NCD	FS	496	N 10 ⁰ 56'00.32" E 76 ⁰ 43'22.26"
N_SC	FS	469	N 10 ⁰ 56'36.0" E 76 ⁰ 43'13.9"
N_MPTI	R	429	N 10 ⁰ 58'38.0" E 076 ⁰ 51'29.0"
N_PER	R	416	N 10 ⁰ 58'45.1" E 076 ⁰ 54'52.0"
N_PBS	P	421	N 10 ⁰ 59'42.3" E 076 ⁰ 55'02.2"
N_WTL	P	421	N 11 ⁰ 00'10.8" E 076 ⁰ 55'19.3"
N_VED1	ST	420	N 10 ⁰ 59'03.08" E 076 ⁰ 54'18.60"
N_VED2	ST	417	N 10 ⁰ 59'06.1" E 076 ⁰ 54'23.0"
N_MUTH1	PT	426	N 11 ⁰ 00'12.8" E 076 ⁰ 55'55.8"
N_MUTH2	PT	422	N 11 ⁰ 00'11.4" E 076 ⁰ 55'38.9"
N_KUR1	ST	405	N 10 ⁰ 58'11.4" E 076 ⁰ 57'27.7"
N_KUR2	ST	402	N 10 ⁰ 57'56.06" E 076 ⁰ 58'09.29"
N_SING1	PT	390	N 10 ⁰ 59'50.49" E 077 ⁰ 01'15.59"
N_SING2	PT	391	N 10 ⁰ 59'08.20" E 077 ⁰ 01'30.72"
Aliyar river basin			
A_ANM	R	251	N 10 ⁰ 34'48.92" E 076 ⁰ 56'19.69"
A_AMB	R	226	N 10 ⁰ 38'15.22" E 076 ⁰ 56'47.97"
A_ATP	R	221	N 10 ⁰ 39'28.75" E 076 ⁰ 55'44.41"
A_KKP	R	204	N 10 ⁰ 38'15.22" E 076 ⁰ 56'47.97"

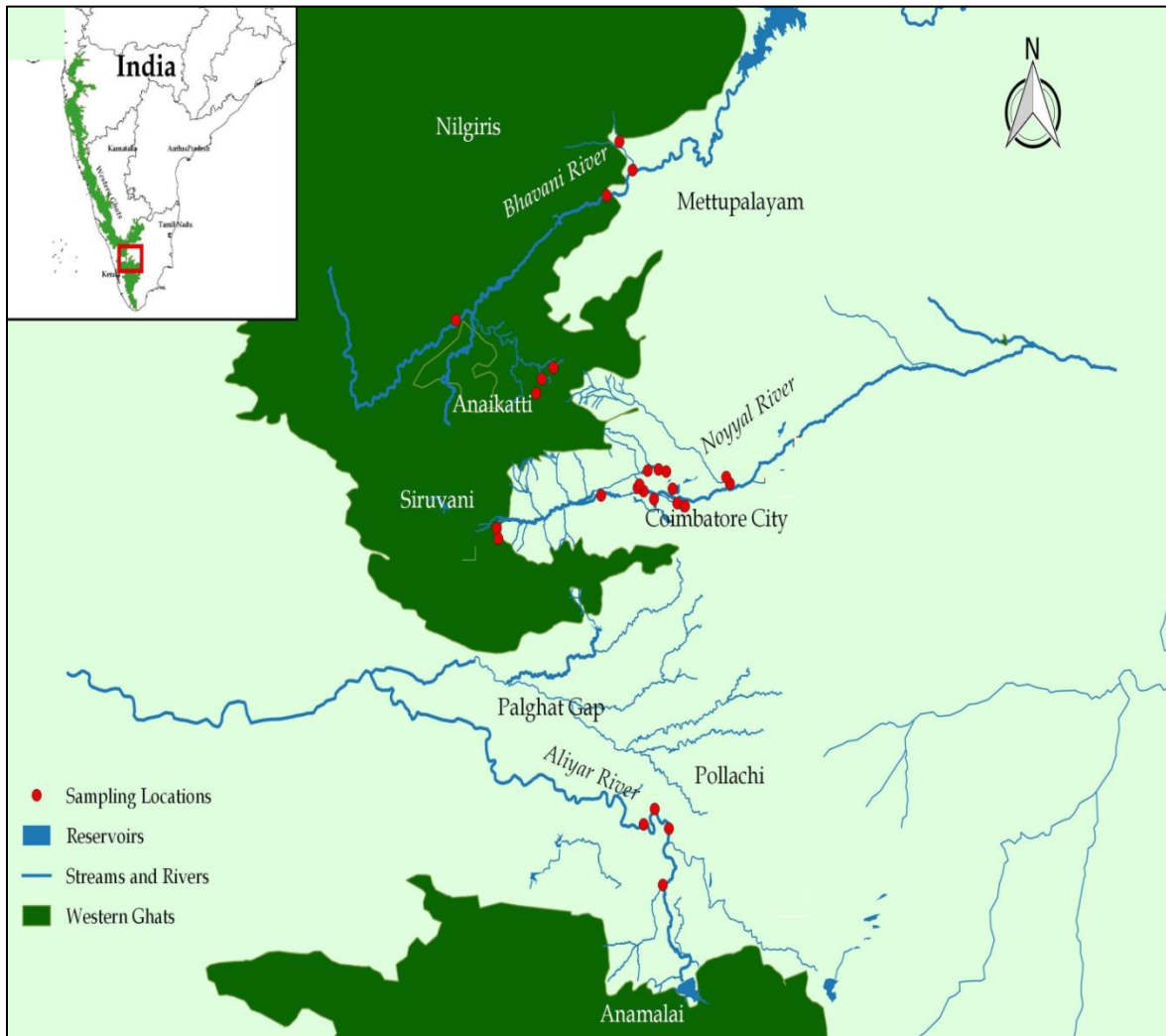


Figure 3.2. Study area and sampling locations



Kallar forest stream (site code: B_KALR)



Bhavani River (site code: B_BKL)



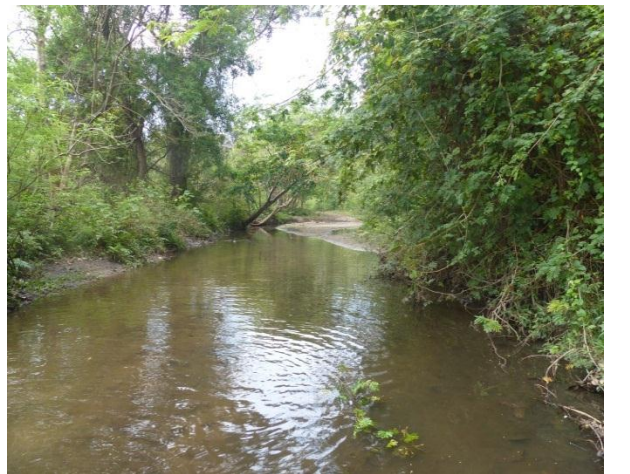
Bhavani River (site code: B_VIL)



Bhavani River (site code: B_CP)



Anaikatty forest stream (site code: B_KOND)



Sadivayal, forest stream (site code: N_CP)

Plate 3.1. Study Habitats of Odonates



Noyyal river (site code: N_PER)



Noyyal river (site code: N_MPTI)



Vedapatty Tank (site code: N_VED1)



Muthanankulam Tank (site code: N_MUTH1)



Kuruchi Tank (site code: N_KUR2)



Singanallur Tank (site code: N_SING2)

Plate 3.1. Study Habitats of Odonates



Paddy Breeding Station (site code: N_PBS)



Wetland Paddy fields, (site code: N_WTL)



Aliyar River (site code: A_ANM)



Aliyar River (site code: A_AMB)



Aliyar River (site code: A_ATP)



Aliyar River (site code: A_KKP)

Plate 3.1. Study Habitats of Odonates

Seasonal tank and Permanent tanks: The seasonal and permanent tanks are a series of irrigational tanks located along the Noyyal River. Totally four study locations in the seasonal tanks and four study locations in the permanent tanks were fixed. The seasonal tanks depend highly on the flow of the Noyyal River. The permanent tanks have a steady inflow from the city's drains, and water is perennial and heavily polluted. There were four study locations from two permanent tanks.

Paddy Fields: Two irrigated paddy fields along the Noyyal River basin were selected. Both of the fields were located in the Tamil Nadu Agricultural University Campus in Coimbatore city. One of the paddy fields was located in the Paddy Breeding Station of the University campus, where various experimental trials on rice is carried out. This study location had a conventional method of cultivation, with inorganic inputs namely, fertilizers and pesticides. The other study location was in the Wetland fields and sampling plot in this location was restricted for only organic method of rice experiments and cultivation.

3.2.2. Sampling strategy

Intensive data collection was done from September 2013 to July 2015. On each sampling day, adult Odonates were counted; physicochemical parameters and other environmental variables were collected during this period. The above mentioned variables were sampled in all 24 study locations once in every two months for two years. Temporally the period was divided into 6 time blocks: June-July (southwest monsoon), August-September (late southwest monsoon), October-November (northeast monsoon), December- January (winter), February-March (pre-summer), April-May (summer). Thus, a total of 287 counts of sampling was carried out. The study site B_KOND alone was sampled 11 times; all the other sites were sampled in all time blocks of the two years (2013-2015) study period.

3.2.3. Field Methods

Adult Odonates were sampled during day time between 9.00 hrs and 16.00 hrs. Odonates were sampled in an area intensive method (William *et al.* 2003) and were counted using direct search method (Sutherland, 1996). In wetland tanks (seasonal and permanent) and paddy fields, 10x10 sq.m plots were fixed and adult Odonates were surveyed five metres on either side from the margin of the water body.

Similarly 50m transects were laid in river and forest stream and one meter on either side of the shoreline was sampled for adult Odonates, covering an area of 100 sq.m. Each count in a sampling location lasted a maximum of 15 to 20 minutes. Both male and female individuals of species were identified; Odonates in tandem and mating positions were also noted. Similarly, oviposition of females was also recorded.

Odonates were identified using standard field guides available: Subramanian (2009), Nair (2011) and Fraser (1933, 1934, 1936). Species which were difficult to identify in the field were captured and photographed. They were later identified with the help of experts in the field.

3.2.4. Environmental variables

All sampling locations were georeferenced using a GARMIN GPS, the altitude of each site was obtained through Google Earth. The following environmental variables (excluding weather parameters) were measured in every sampling location (Table 3.2). Weather parameter (maximum temperature (°C), rainfall (mm), relative humidity (%)) data for each sampling unit were obtained from the nearest automatic weather station nearest to the study location was obtained from Tamil Nadu Agricultural University (TNAU) meteorological department.

Measurement of water variables was carried out using a hand held water probe (EUTECH-Multi-purpose meter). Water temperature (°C), pH, conductivity (μ S), total dissolved solids (ppm) and salinity (ppm) were measured. Due to the collinearity between the variables of conductivity, TDS and salinity, all the three being measures of salinity, only conductivity was taken into account for analyses. The flow rate of water, whether it is stagnant, gliding, rapid or dry was noted as a categorical variable. Other environmental variables were obtained by observations made in the field in the form of percentages (Table 3.2).

3.2.5 Data analyses

Details of statistical analyses performed are given in the respective chapters under the relevant study.

Table 3.2 Environmental variables observed in the study

Variables	Method
Weather parameters	
Maximum atmospheric temperature (°C)	Obtained from the nearest automatic weather station to the sampling point (TNAU Met dept)
Relative humidity (%)	
Rainfall (mm)	
Wind speed (km/hr)	
Water measures	
Water temperature(°C)	EUTECH-Multi-purpose meter
pH	EUTECH-Multi-purpose meter
Conductivity (µS/cm)	EUTECH-Multi-purpose meter
Total dissolved salts(ppm)	EUTECH-Multi-purpose meter
Salinity(ppm)	EUTECH-Multi-purpose meter
Flow rate	Visual observation
Physical and biological attributes	
% Shade	Visual observation
% Surface rocks	Visual observation
% Sandbanks	Visual observation
% Exposed soil	Visual observation
% Native shrubs	Visual observation
% Invasive shrubs	Visual observation
% Grass	Visual observation
% Reeds	Visual observation
% Aquatic macrophytes	Visual observation
% Water Hyacinth	Visual observation

CHAPTER 4

ODONATE COMMUNITY PROFILE AND SPECIES COMPOSITION

4.1. INTRODUCTION

Freshwater ecosystems across the world are under tremendous anthropogenic pressure and there is an urgent need to assess the quality of these freshwater habitats using repeatable and quantitative assessment of macro-invertebrates. The power of bio-monitoring of freshwater ecosystem using insects can be attributed to the wide variation in tolerance to specific pressures of the ecosystem (Gray *et al.* 2015). Bonada *et al.* (2006) made a comparative analysis of various biomonitoring approaches considering the importance of freshwater ecosystems especially in rivers and streams. Friberg *et al.* (2011) reviewed the pros and cons of current methods of biomonitoring at different levels of organisation and recommended to have careful considerations of both responses (bio-indicators) and drivers (stresses) while making management decisions. As in other countries, awareness is being created to conserve the freshwater ecosystems using various fauna as bioindicators (Saha *et al.* 2016). Aquatic insects are considered as one of the biomonitoring resources for freshwater ecosystems and methodologies have been developed (Subramanian and Sivaramakrishnan, 2007). In this process of identifying the bioindicators, taxonomic resolution of the aquatic insect to be employed should be given priority (Bush *et al.* 2012). Among the freshwater insects, odonates receive more attention because of their long standing history on the biology of the insect concerned (Khelifa *et al.* 2017) and they are also used as bioindicators of freshwater ecosystems (Clarke and Samways, 1996; Samways and Steytler, 1996; Subramanian, 2009).

In India there are many endemic odonate fauna restricted to the four biodiversity hotspots *viz.* the Western Ghats, Western Himalaya, Indo-Burmese (includes Andaman Islands) and Sundaland including Nicobar Islands (Babu *et al.* 2013). Among the four hotspots, the endemic forms of Odonates of peninsular India including Western Ghats are well documented along with their habitat distribution and threats (Subramanian, 2007; Mitra *et al.* 2011; Subramanian *et al.* 2011). Dragonflies and damselflies (Odonata) are known to have high diversity and endemism in the Western Ghats (Subramanian *et al.* 2011; Babu *et al.* 2013). It is reported that out of 174 odonates species in Western Ghats, 69 are endemic to the

region and are mostly found in riverine habitats such as montane streams and rivers with large portion (82%) surviving exclusively in riverine habitats (Molur *et al.* 2011; Radhakrishnan and Rajmohana, 2012). Numerous studies on the Odonates of Western Ghats have been published recently (Rangnekar *et al.* 2010; Kiran and Raju, 2013; Verghese *et al.* 2014; Adarsh *et al.* 2015; Tiple and Koparde, 2015). With all these efforts, studies were also conducted on Odonates for their range extension (Das *et al.* 2013), species additions (Rangnekar *et al.* 2010; Emiliyamma *et al.* 2012, 2013; Rangnekar and Naik 2014) and new species description (Subramanian *et al.* 2013). The report of International Union for Conservation of Nature (IUCN) indicated that the main threats impacting freshwater biodiversity, especially Odonate biodiversity in the Western Ghats include: a) pollution, b) biological resource use, c) residential and commercial development, d) dams and other natural system modifications and e) agriculture and aquaculture impacting 21 per cent, 7 per cent, 11 per cent, 4 per cent and 7 per cent of odonates respectively (Molur *et al.* 2011).

Surrounded by the Western Ghats, Coimbatore exhibits varied landscapes, vegetation and aquatic bodies suitable for a rich diversity of Odonates. Odonates in this region were first documented by Fraser (1931, 1933, 1934, 1936) enlisting 48 species in addition to six more species by Ayyar and Ayyar (1933). A total of 23 species has been documented from the insect collection of Agricultural College and Research Institute, Coimbatore (Abraham, 1959), of which two species were additional records to the already documented list. Studies conducted in this region from 1999 onwards resulted in the documentation of 22 species from the paddy fields of Coimbatore (Gunathilagaraj *et al.* 1999; Chitra *et al.* 2002); 23 species from tanks (Arulprakash and Gunathilagaraj, 2010a; Karthika and Krishnaveni, 2014); seven species from Bhavani River (Arulprakash and Gunathilagaraj, 2009) and seven species from other opportunistic observations (Arulprakash and Gunathilagaraj, 2010b). These checklists provide an addition of 13 species to the district. The checklists of the Odonate fauna from various forest reserves and wildlife sanctuaries *viz.*, Silent Valley National Park (Rao and Lahiri, 1982), Parambikulam (Emiliyamma and Radhakrishnan, 2000), Thattekad (Varghese *et al.* 2014), Chinnar Wildlife Sanctuary (Adarsh *et al.* 2015) adjoining to Coimbatore have also been made to establish the wealth of Odonates in this region.

Published catalogues of Odonates of Coimbatore cover limited habitats and areas of the district. Given the wide geographical extent of the district and its varied habitats, the aim of the present investigation was to catalogue Odonates from various aquatic bodies in Coimbatore, covering forest streams, river, irrigational tanks, ponds and paddy fields. This chapter provides the details of extent of endemism and species richness in the study with a consolidated list of species recorded from the survey and from previously available literature.

4.2. METHOD

4.2.1. Data analysis

The Odonate survey method is elaborately discussed in Chapter 3. The data presented here includes the list of species observed from reconnaissance survey (September, 2012-July, 2013); seasonal surveys of 24 intensive study locations, conducted once in every two months from September 2012 to July 2015 and opportunistic observations. The list of all locations surveyed during the study is furnished in Appendix 1. Historical records on Odonates from Coimbatore district and from recent publications are also considered in this chapter.

The Species Accumulation Curve (SAC) was constructed using the software EstimateS version 9.1 (Colwell, 2013) by Chao2 and Jackknife2 to explain the presence or absence of (incidence) species in the study area. The Rank Abundance Curve (RAC) values were constructed to have the regional richness involving the 5525 individual observations across the 24 sampling units.

4.3. RESULTS

4.3.1. Community composition

A total of 70 species belonging to 11 families of Odonates was recorded in the present study including 18 species as first time records to the Coimbatore district. Of the 18 first time records, the species identity of the *Gomphidia (cf)* was not established. Of the 70 species, 47 fell under the sub-order Anisoptera and the rest 23 species under suborder Zygoptera. Among the 70 species recorded (Appendix 2), 37 species (53%) were found to be under Libellulidae and 11 species (16%) were found to be under Coenagrionidae making both the families most species rich under

Anisoptera and Zygoptera, respectively. The third most species rich family was Gomphidae with six species (9%). The number of species recorded in the rest of the families include: four under Aeshnidae, three under Calopterygidae and two each under Chlorocyphidae, Euphaeidae and Platynemididae. The families namely, Platystictidae, Lestidae and Protoneuridae included one species each. Among the habitats, forest streams were found to be rich with a total of 11 families followed by rivers with 10 families. There were four families from tanks and only two families from the paddy fields. The family-wise distribution of Odonate species recorded across the study area is furnished in the Figure 4.1.

The distribution of species were found to be overlapping between four habitats viz., forest streams, rivers, tanks and paddy fields. Among the 47 species of Anisoptera, 40, 30, 26 and 12 species were distributed in the habitats viz., forest streams, rivers, tanks and paddy fields, respectively. Similarly 23 species of Zygoptera showed overlapping distribution across forest streams (17 species), rivers (17 species), tanks (8 species) and paddy fields (5 species).

Out of 18 first time records from this study, *Indothemis carnatica* was recorded in the stagnant ponds of Boluvampatti and Anaikatty forest. Whereas one species under the genus *Gomphidia cf.* was sighted in the Bhavani River near Mettupalayam for which the authentication could not be established. Crepuscular species like *Anaciaeschna jaspidea* and *Zyxomma petiolatum* were recorded at light sources. The damselfly, *Euphaea dispar*, was also recorded in the fast flowing cascade in Siruvani forest, Coimbatore (550m). The endemic *Pseudagrion indicum* was observed only once in a swamp near Siruvani forest.

4.3.2. Species richness

The number of different species representing the four different habitats viz. forest streams, rivers, tanks and paddy fields were recorded based on the counting of Odonates from 24 intensive sampling locations during the study period (2013-2015). The cumulative number of species of Odonates across the four habitats were found to be 63 in 5525 individuals recorded from the samples collected during the study period. The Species Accumulation Curves (SAC) constructed based on the observations in time involving Chao2 and Jackknife2 predicted the number of species as 71.83 (\pm 6.32) and 79.94, respectively and reached asymptote (Figure 4.2). In the

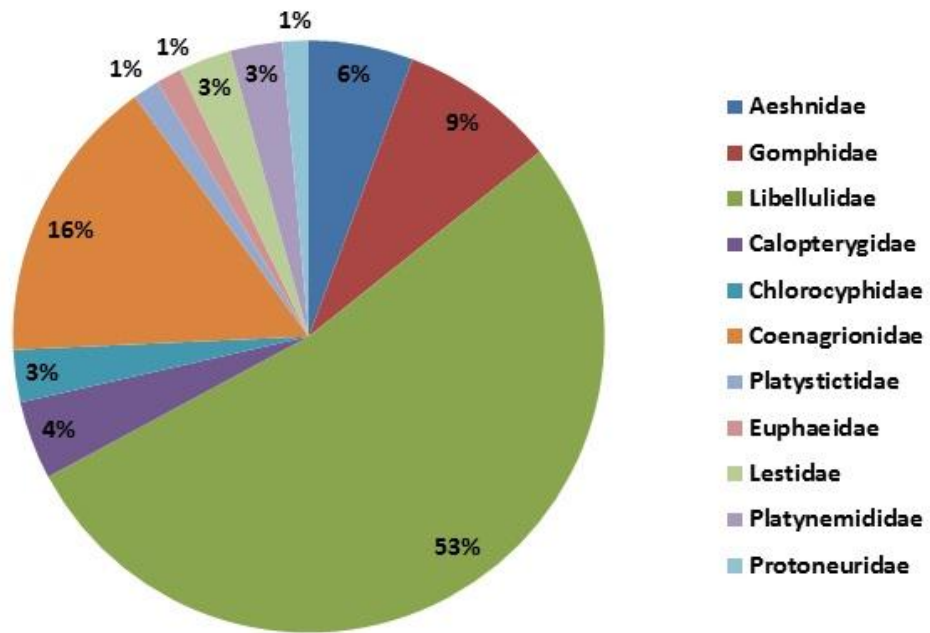


Figure 4.1. Family-wise occurrence of Odonate species across the study area

present study a total 70 species were recorded which included seven species from opportunistic observations.

Of the 63 species observed across the habitats, seven species accounted for nearly 60% of the total Odonate encounters in the systematic sampling. *Pantala flavescence* (13% of total abundance) was found to be the most abundant species followed by *Brachythemis contaminata* (11%), *Crocothemis servilia* (7.2%) and *Coeragrion coramandelianum* (7.2%). The species abundance for the study region is shown in the Rank abundance curve constructed based on the observations (Figure 4.3). A total of eight and seven species were recorded in singletons and doubletons, respectively from the present study.

With the inclusion of new records of Odonates, the total number of species in the region comes to 87. Of them, species from Anisoptera (58 species) were found to be higher than the species from Zygoptera (29 species) (Plates 4.1 and 4.2).

Of these 87 species (excluding the unconfirmed *Gomphidia cf sp*), 64 species were found to be under the 'Least Concern' category of the IUCN Red list. Four species viz., *Burmagomphus laidlawi* and *Gomphidia kodaguensis* of Gomphidae, *Pseudagrion indicum* of Coenagrionidae and *Dysphaea ethela* of Euphaeidae were found to be under the 'Data deficient' category. *Indothemis carnatica* belonging to Libellulidae, is the only species from the present survey which was found to be under the Near Threatened list of IUCN.

4.3.3. Endemicity

A total of 14 endemics were recorded in the present study. Out of the 47 species of Anisoptera observed in the present study, four are endemic. All four species are endemic to the Western Ghats (three species and one subspecies). Under Zygoptera, ten species (eight species and two sub-species level) and four were endemic to the Western Ghats (three species and one sub-species). Both in forest streams and rivers, 10 endemics were recorded. No endemics were recorded from the tanks and paddy fields. Including earlier records, a total of 22 species (12 Zygoptera and 10 Anisoptera) from Coimbatore district are endemic (16 species and 6 subspecies level), of which 14 are endemic to the Western Ghats (11 species and 3

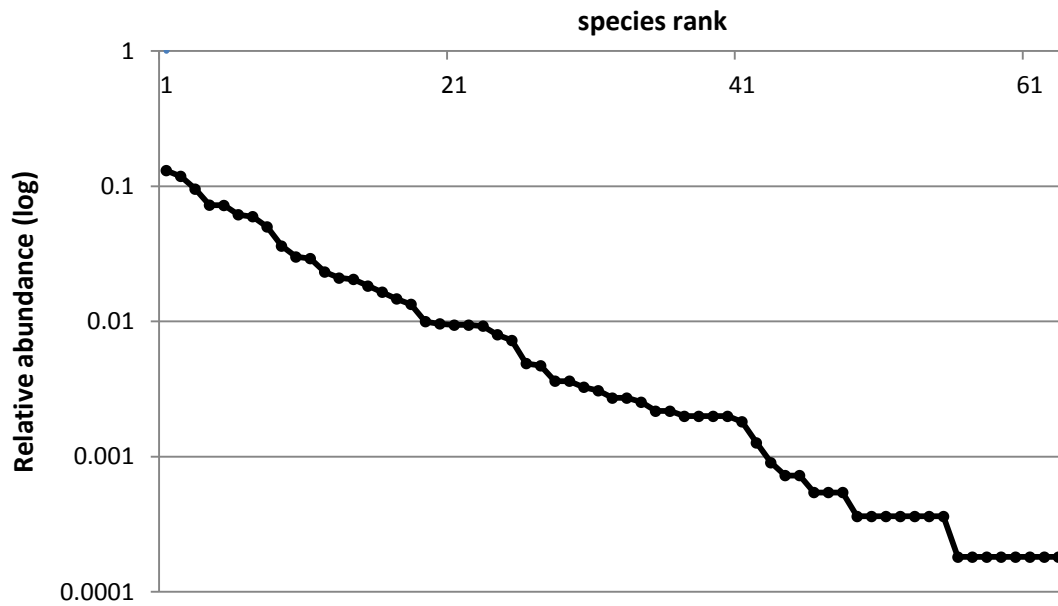


Figure 4.2. Rank abundance or Whittaker Plot for Odonates observed during 2013-2015

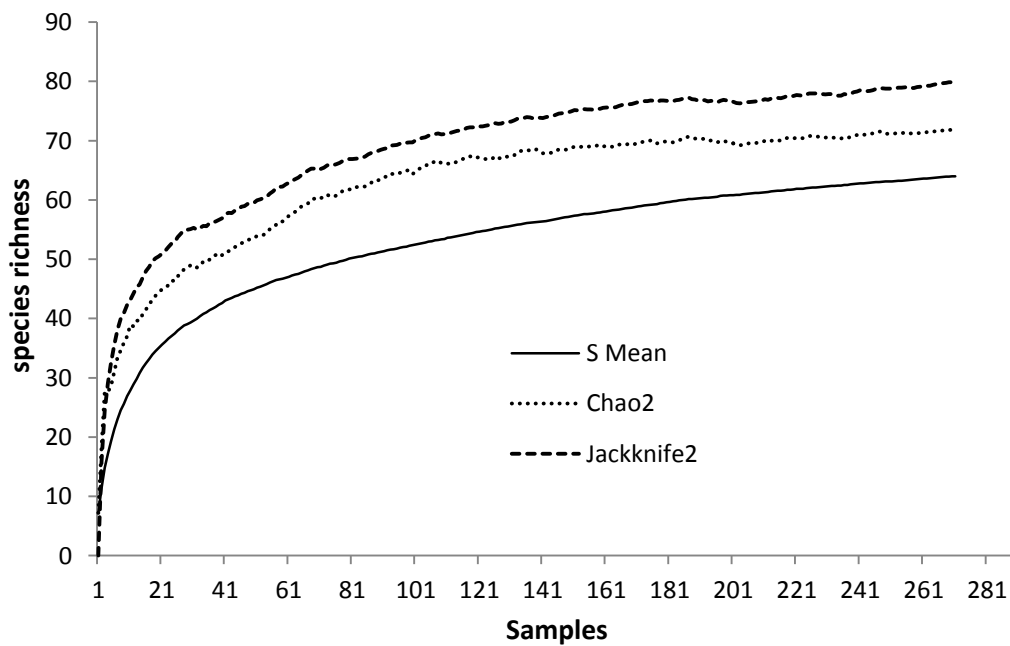


Figure 4.3. Species Accumulation Curve based on adult Odonate sampling in Coimbatore district, during 2013-2015



Anax immaculifrons



Anaciaeschna jaspidea



Burmagomphus laidlawi



Ictinogomphus rapax



Onychogomphus nilgiriensis



Paragomphus lineatus



Gynacantha dravida



Brachydiplax chalybea



Brachydiplax sobrina



Crocothemis servilia



Acisoma panorpoides



Lathrecista asiatica

Plate 4.1. Dragonflies recorded during the study period



Neurothemis tullia



Onychothemis testacea



Orthetrum pruinosum



Orthetrum luzonicum



Orthetrum chrysis



Orthetrum glaucum



Trithemis kirbyi



Trithemis festiva



Trithemis aurora



Tramea basilaris



Orthetrum taeniolatum



Potamarcha congener



Rhodothemis rufa



Rhyothemis variegata



Tetrathemis platyptera

Plate 4.1. Dragonflies recorded during the study period



Neurobasis chinensis



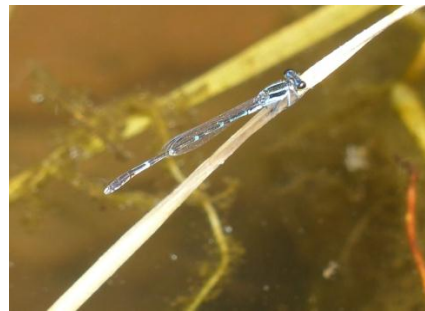
Vestalis apicalis



Dysphaea ethela



Rhinocypha bisignata



Agriocnemis splendidissima



Euphaea dispar



Prodasineura verticalis



Libellago lineata



Pseudagrion indicum



Lestes elatus



Copera marginipes



Copera vittata

Plate 4.2. Damselflies recorded during the study period

sub-species level) (Appendix 2). The species distribution across the study area and the extent of endemism are furnished in Figure 4.4.

4.4. DISCUSSION

Coimbatore District is known for its richness in biodiversity due to its location next to the Western Ghats. The rivers, tanks and wetlands in this region form a luxurious freshwater aquatic habitats for the sustenance of several beneficial fauna and flora. Among them, Odonates, one of the predatory insects, exhibit rich biodiversity in this district because of the regions varied landscapes and aquatic habitats. The number of species recorded in the region shows an equally high degree of richness when compared to other regions in the Western Ghats (Kiran and Raju 2013; Varghese *et al.* 2014; Adarsh *et al.* 2015).

In the present study, a total of 70 species from 11 families of Odonates were recorded including 18 species as first time records to the Coimbatore district. Of the 70 species, 47 belonged to Anisoptera and the rest 23 species were under Zygoptera indicating the predominance of Anisoptera over Zygoptera. The estimated species richness for Odonates in this region indicated that the number of Anisoptera species was higher than the species under Zygoptera and the same was established based on the earlier studies conducted in and around Coimbatore district (Arulprakash and Gunathilagaraj, 2010a; Adarsh *et al.* 2015; Emiliyamma and Radhakrishnan 2003; Varghese *et al.* 2014). The earlier records of Fraser (1931, 1933, 1934, 1936) also indicated the higher level occurrence of Anisoptera over Zygoptera. The environmental and spatial effects including temperature and climate in a region affect the dispersal ability and inturn the distribution of species (Heiser and Schmitt, 2010).

The abundance of Anisoptera over Zygoptera can be attributed to the distinct morphological and ecophysiological characteristics of Anisoptera and Zygoptera (Corbet, 1999). These factors could influence the dispersal ability of these two groups of insects, wherein Anisoptera could possess greater dispersal ability over Zygoptera due to their lesser susceptibility to the environmental disturbances (Corbet, 1999). Cordoba-Aguilar (2008) attributed interspecific variation could be another reason for the predominance of Anisoptera over Zygoptera. According to Opiel (2005) and Jomoc *et al.* (2013), closed forest conditions favour Zygoptera. High Zygoptera to Anisoptera ratio has been observed in forest landscapes (Opiel, 2005). Yet, in the

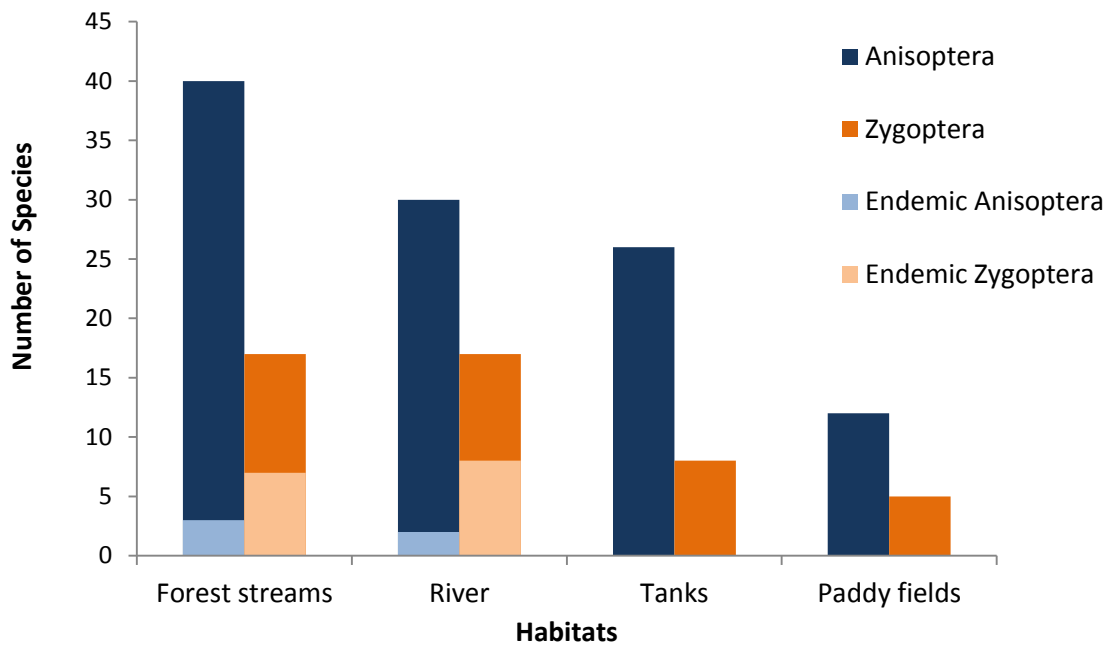


Figure 4.4. Total species richness and endemics observed from the aquatic habitats

present study, Anisopetra were predominant over Zygopetra and it could be because the study area did not cover much core forest area.

Many of the first time records from the present study have been observed from various adjoining regions of Coimbatore: the Nilgiris, the Anaimalai and Palani hills (Fraser 1923, 1924, 1931, 1933, 1934 and 1936; Rao and Lahiri 1972; Verghese *et al.* 2014; Adarsh *et al.* 2015). Though there were first time records, some of the already recorded species were not observed in the study area and they include a total of 16 species observed by Fraser (1931, 1933, 1934, 1936); Ayyar and Ayyar (1933); Gunathilagaraj *et al.* (1999) and Arulprakash and Gunathilagaraj (2010b) (Table 4.1).

The species observed by Fraser in 1930s but were not observed in the present survey include *Asiogomphus nilgiricus*, *Heliogomphus promelus*, *Megalogomphus superbus*, *Microgomphus souteri*, *Macromia cingulata*, *Macrodiplax cora*, *Protosticta sanguinostigma*, *Caconeura t-coerulea* (Fraser 1931, 1933, 1934, 1936). The species *Megalogomphus superbus* recorded in the Coimbatore forest and *Caconeura t-coerulea* in the Mettupalayam ghats and Nilgiris remain to be the only record of these species (Fraser, 1933). *Macrodiplax cora* a species recorded mostly in coastal areas and occasionally in inland was found nearly in every bush in Coimbatore district according to Fraser (1936). However, this species was not recorded during this study. Among the habitats, forest streams were found to be rich with a total of 11 families followed by riverine sites with 10 families.

There were records of four families from tanks and two families from paddy fields and these habitats did not hold any endemic species. This could be due to human activities, habitat destruction, eutrophication, acidification, and pollution of aquatic habitats (Kalkman *et al.* 2008). Low endemism in Odonates, has been reported in the areas with intensive agricultural activities, resulting in the habitat destruction (Naik and Sayeswara, 2017). Forest habitats hold the highest number of species followed by riverine sites. Both these habitats hold the highest number of endemics as well.

Members of the families like Calopterygidae, Chlorocyphidae, Euphaeidae, Platystictidae were reported to solely occupy lotic systems (Corbet, 1999; Corbet *et al.* 2006). Similarly, in the present study, the members of these families were recorded from forest streams and river sites. Three species *viz.*, *Neurobasis chinensis*, *Vestalis*

Table 4.1. List of species recorded earlier but not observed in the present study

Species	Habitat	Record by
Aeshnidae		
<i>Anax parthenope</i> Selys, 1839	T	F ²
<i>Hemianax ephippiger</i> Burmeister, 1839	P	TK, AB, AG ³
Gomphidae		
<i>Asiagomphus nilgiricus</i> Laidlaw, 1922**	R	F ²
<i>Heliogomphus promelas</i> Selys, 1873**	F	F ²
<i>Megalogomphus superbus</i> Fraser, 1931**	F	F ¹
<i>Microgomphus souteri</i> Fraser, 1924**	F	F ¹
Libellulidae		
<i>Macrodiplax cora</i> , Brauer, 1867	F,R,T	F ³
<i>Neurothemis fulvia</i> Drury, 1773		TK, AB
Macromiidae		
<i>Epophthalmia vittata</i> Burmeister, 1839*	F	F ³
<i>Epophthalmia frontalis</i> Selys, 1871**	F	F ³ , AG ³
<i>Macromia cingulata</i> Rambur, 1842		F ³
Coenagrionidae		
<i>Aciagrion occidentale</i> Laidlaw, 1919	F	F ²
<i>Argiocnemis rubescens</i> Selys, 1877	P	G
<i>Coeragrion cerinorubellum</i> Brauer, 1865	P	G
Platystictidae		
<i>Protosticta sanguinostigma</i> Fraser, 1922*	F	F ³
Protoneuridae		
<i>Caconeura t-coerulea</i> Fraser, 1931**	F	F ³

Record references: **F¹**- Fraser 1924; **F²**- Fraser 1931; **TK**- T. Ramakrishna Ayyar and Krishna Ayyar 1933; **F³**- Fraser- (1933-36); **AB**- (Abraham, 1959); **G**- Gunathilagaraj *et al* 1999; **AG¹**- Arulprakash & Gunathilagaraj 2009; **AG²**- Arulprakash & Gunathilagaraj 2010a; **AG³**- Arulprakash & Gunathilagaraj 2010b; **KK**- Karthika & Krishnaveni 2014; **MP**- Muhil & Pramod (Present study).

* Endemic to India; ** Endemic to Western Ghats; **F**-Forest Streams; **R**-Rivers; **T**- Tanks and Ponds; **P**- Paddy fields.

apicalis and *V. gracilis* belonging to the family Calopterygidae (forest dependent damselflies) were observed only in forest and riverine areas as indicated by Cordoba-Aguilar and Rivera (2005). However, *Vestalis apicalis* and *V. gracilis* was observed far away from river and forest streams by Arulprakash and Gunathilagaraj (2010b) and the occurrence of these forest dependent species away from streams and rivers, the authors suggest could be attributed to their aestivation. Similarly, *Trithemis aurora* a species predominantly found in streams and rivers were occasionally observed in paddy fields (Arulparakash and Gunathilagaraj 2010b). *Euphea dispar*, is a species found in higher elevations (Kakkasery, 2011) and in this study, this species was observed in a lower elevation of (550msl). Fraser (1924) suggests that the competition from *E. fraseri* (a lower elevation species), drives the former species to higher elevations and on *E. fraseri*'s absence this species is observed in lower elevations. The above results clearly indicated that the species dispersability in Odonates depends on the environmental sensitivity and species interaction between Odonates as reported by Corbet (1999) and Heiser and Schmitt (2010).

In ecology, different methods are used to assess the species diversity in living organisms. Among the methods, species richness is one of the components which explains the number of different species represented in an ecological community, landscape or region (Colwell and Coddington, 1994). In the present study, Species Accumulation Curve reached asymptote, indicating the adequacy of observations for deciding the species richness in the study area. The gradual sloppiness of the Whittaker Plot established, indicated high evenness and suggesting that the abundance of many species are similar.

In the present study, attempts were made to cover a wide range of aquatic habitats in the district excluding the Anamalai hills which lie in the southern most part of the district. Likewise, certain distributional records of Odonates by Fraser (1931) from the Anamalai hill and Mudi hills (High ranges) together could not be confirmed as the exact location of species could not be demarcated. Moreover, the Anamalai range as a whole posses a rich Odonate entity, which at present requires a rigorous assessment seperately. Similarly, an extensive list of Odonates has been recorded from the Kallar and Burliyar rivers (tributaries of Bhavani, Nilgiri District). Some of the species recorded here include, *Idionyx buraliyaarensis*, *Idionyx nilgiriensis*

(Fraser, 1926), *Euphaea fraseri* (Fraser, 1931; Abraham, 1959), *Onychogomphus striatus* and *Hylaeothemis indica* (Fraser, 1931).

The Palghat gap in the study area is known to be a geographic barrier for many taxa, in the mountains either side of the gap (Daniels, 1992; Robin *et al.* 2010; Klaus *et al.* 2014). The same status was established in high altitude Odonate assemblage study by Fraser (1923), who indicated that the gap distinctly divides the Odonate faunal group into northern and southern groups. Fraser (1931) also reported that the direction of flow of rivers in this region could influence the segregation of Odonates into eastern and western groups. Considering this, studies can be intensified in the rivers flowing east and west of Coimbatore district and also in the high altitudes to establish the above observations. The consolidated list of 87 species, indicates the rich Odonate diversity in Coimbatore. More species can be expected from this region considering the fact that the region supports varied landscapes and drainages. This region along with core areas of Siruvani hills may hold additional species, which needs to be revisited.

4.5. CONCLUSION

From the field survey of 287 counts in 24 study locations of Coimbatore, between September 2013 to July 2015, 70 species of Odonates were recorded, of these 18 species are first time records to the region. Among the different habitats, the forest streams and river locations, 14 endemics have been recorded in the present study. The number of Odonate in Coimbatore lists to 87 species with 22 endemics, which indicates the rich diversity of Odonates in comparison to the studies along the Western Ghats. Despite, intensive sampling of various aquatic habitats in Coimbatore for over two years, a total of 16 species from earlier records by Fraser (1933, 1934, 1936) were not recorded in the present study indicating probable change in habitat conditions in the district over the years.

CHAPTER 5

DIVERSITY AND DISTRIBUTION OF ODONATES IN SPACE AND TIME

5.1 INTRODUCTION

Odonate diversity varies in space and time just as other faunal components. Species diversity and distribution of Odonates assemblages are known to be influenced by geological and ecological factors (Kalkman *et al.* 2008). The ecological factors which limit Odonate distribution, is its dispersal ability and the environmental heterogeneity of the region in local and regional scales (Andersson, 2006). The distribution of Odonates has several underlying processes in space and time (Suhling *et al.* 2009). While, the ability of Odonates to disperse could be due to over-population and habitat constraints Corbet (1962), the factors which constrain the distribution of species causes not just varied spatial distribution of assemblages but also varied temporal distribution of assemblages (Korhonen *et al.* 2010).

Diversity within an ecosystem is a predictor of its stability and the efficiency of its ecosystem (MacArthur, 1955). Diversity measures are classified as species richness measures and heterogeneity measures (McIntosh, 1967). Heterogeneity measures combine richness and evenness components of diversity (Magurran, 2004). The diversity and distribution of species in space and time are not the sole factors influencing the assemblage pattern of a taxon. Other factors such as the body size of the species, its position in the food web and the predator-prey relationship in the region, all influence diversity. Body size is a fundamental determinant of species' ecology (Worthen and Jones, 2006). Also, the presence or absence of individual species is a reflection of its habitat conditions and success in interspecific interactions (Allan and Castillo, 2007).

Odonates are good indicators of habitats, and many studies have assessed terrestrial landscapes using these organisms (Buchwald, 1992; Stewart and Samways, 1998). Long term seasonal studies on Odonates have given insights on their potential to monitor climate change in landscapes (Bush *et al.* 2012). The fact that Odonates need freshwater bodies for oviposition and larval development makes them strongly dependent on freshwater environments and seasonality is an important factor influencing the occurrence and distribution of populations (Corbet, 1999; Dijkstra *et al.* 2014). Temporal variation is essential in monitoring Odonates (Balzan, 2012). Dragonflies are excellent indicators of river disturbance and biotope type and encapsulate general trend in changes in biodiversity that

physical river measurements would not provide (Stewart and Samways, 1998). In India there are studies related to habitat assessment of dragonflies (Das *et al.* 2006; Andrew *et al.* 2008) but studies related to seasonality are scarce. The aim of this chapter was to assess the diversity of Odonates in different aquatic habitats and understand its spatial and temporal distribution.

5.2. DATA ANALYSES

Mean species richness and mean abundance of Odonates were calculated for all study locations, habitats, river basins and seasons. One-way Analysis of Variance (ANOVA) was used to test if there was significant difference in species richness and abundance between the habitats and similarly between the seasons. Abundance, in this chapter is defined as the total number of individuals encountered from a sample. Other alpha diversity measures such as Shannon-Weiner index, Simpson index, Buzas and Gibson's evenness measure and Fisher's alpha were assessed among different habitats and locations.

Shannon index is one of the most enduring of all diversity indices (Magurran, 2004). The Shannon-Weiner index takes into account the number of individuals and number of taxa. The Shannon index is calculated from the equation:

$$\text{Shannon index (H')} = -\sum p_i \ln p_i$$

Where p_i is the proportion of individuals found in the i^{th} species.

Dominance and evenness measure are weighted based on the abundance of the commonest species (Magurran, 2004). An assemblage with equally abundant species will have high evenness. The Buzas and Gibson's evenness measure expresses how evenly, the proportion of a taxa is distributed in a sample.

$$\text{Buzas and Gibson's evenness measure} = e^{H'/S}$$

Where H' is the Shannon index and S is the species number. Simpson (1949) gave the probability of any two individuals drawn at random from an infinitely large community belonging to the same species. As dominance (D) increases diversity decreases. Simpson index is therefore usually expressed as $1-D$ or $1/D$.

$$D = \sum p_i^2$$

Fisher's alpha diversity index is insensitive to sample size (Fisher *et al.* 1943), and is defined by the formula

$$S=a*\ln(1+n/a)$$

where S is number of taxa, n is number of individuals and a is the Fisher's alpha. The diversity indices were calculated using the software PAST 3.1 (Hammer *et al.* 2001).

Species Richness among the aquatic habitats was examined by constructing Species Accumulation Curve, along with the richness estimator Chao2 using EstimateS 9.1 (Colwell, 2013). If the curve reaches an asymptote, it indicates that sampling was sufficient and it is less likely that more species would be added. When the curve does not reach an asymptote, there is a likelihood that additional species could be present and that sampling is insufficient. Rank abundance curve (Whittaker plot) was constructed using log abundance and ranked species sequence (Whittaker, 1965). The rank abundance curve displays both species richness and evenness. The relative abundance of the ten most abundant species from each aquatic habitat was also plotted.

Distribution of Odonates based on body size was examined using the abdominal and hindwing length of males and female Odonates. The morphometric data was obtained from Fraser (1933, 1934 and 1936). Frequency distribution of the abdominal length and hindwing length of all the species based on the number of individuals recorded were drawn. Similarly, a scatter plot was plotted to visualise the species abundance distribution based on body size.

The following methods were used to analyse the Beta diversity of aquatic habitats and seasons.

Non-metric Multidimensional scaling is an ordination technique which provides a visual representation of the similarity in the community data set. The similarities among aquatic habitats based on the ecological communities are graphically represented, using Bray-Curtis index and Jaccard index. Sites with similar composition are located close to each other, and those which are less similar will be located farther apart. A stress value of <0.1 is considered as a good ordination. Similarities in Odonate composition between seasons were assessed using UPGMA (Unweighted pair group arithmetic average) cluster analyses using Bray-Curtis index. Similarly, the analysis of similarity for species composition at different seasons and aquatic habitats was statistically derived by ANOSIM (Clarke and Green, 1988). Analysis of similarity (ANOSIM) is a non-parametric method to assess the variation in

community assemblages. ANOSIM operates through dissimilarity matrices. To explore the contribution of individual species on the dissimilarity between two assemblages was analysed through SIMPER (Similarity Percentage).

Bray-Curtis similarity index and Jaccard similarity index were used to examine the similarity between study locations. A pair-wise comparison between each site was made. The values range from 0 to 1. Values closer to '0' indicate highly dissimilar assemblages and '1' indicates complete turnover of species. All the above analyses were carried out using PAST 3.1 (Hammer *et al.* 2001).

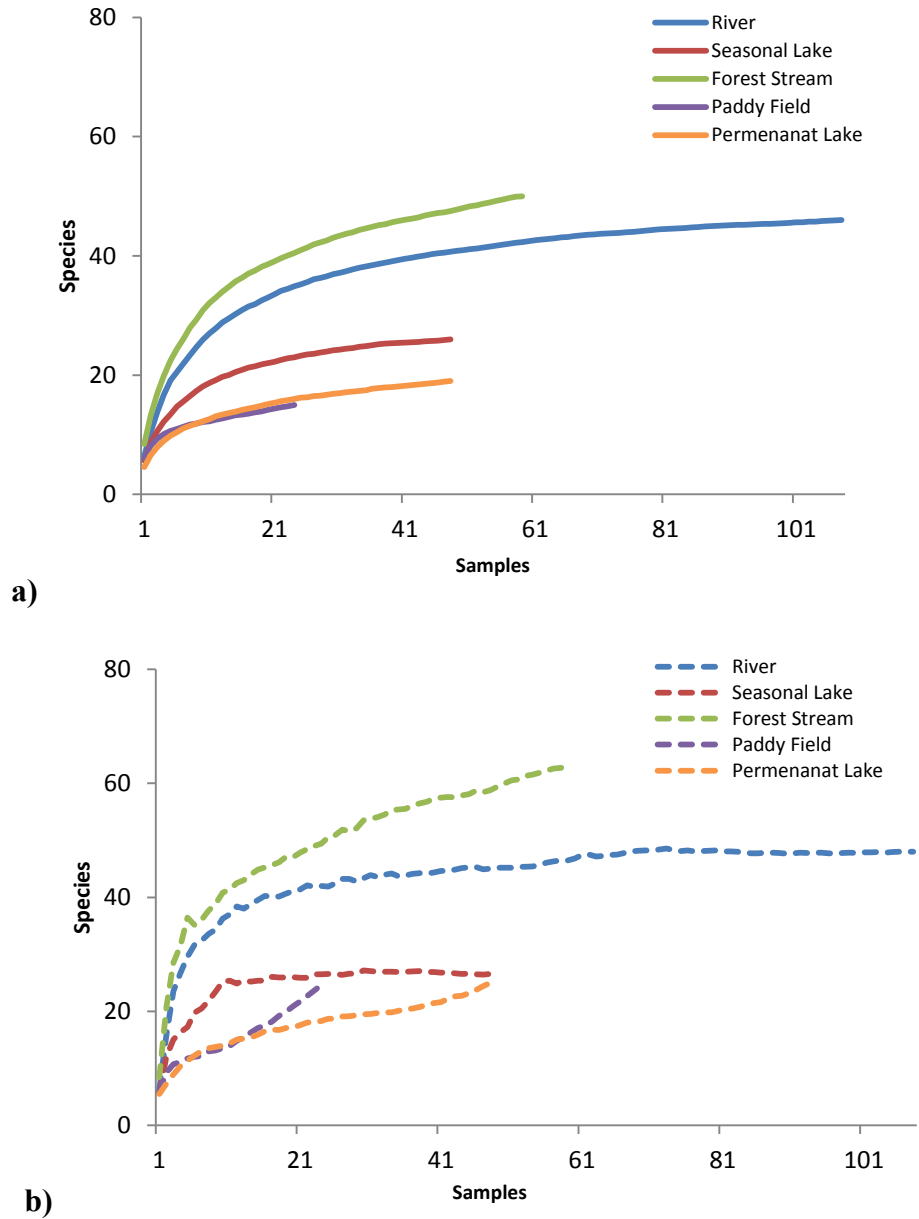
5.3. RESULTS

5.3.1 RICHNESS AND DIVERSITY

A total of 50 species was recorded from the forest streams; 46 species from rivers; 26 species from seasonal tanks; 19 species from permanent tanks and 15 species from paddy fields. The Species accumulation curve constructed across the habitats reached an asymptote indicating the adequacy of sampling (Figure 5.1 a). The Chao2 richness estimator predicted the number of species could be higher than the observed species in forest streams (62.8), permanent tanks (25.0) and paddy fields (24.6) (Figure 5.1 b).

From the sampling locations of Noyyal and Bhavani rivers, 49 species of Odonates were recorded individually. A total of 38 species were observed from the sampling locations of Aliyar river. Among the aquatic habitats, species richness was highest in forest streams (7.49 ± 3.73) followed by river (6.73 ± 3.21) and the lowest in permanent tanks (3.56 ± 1.48). There was significant difference in species richness between the aquatic habitats (ANOVA $F_{4,23} = 5.94$, $p = 0.003$). Among the rivers, Alaiyar river had the highest mean species richness (7.14 ± 2.85) followed by Bhavani river (5.87 ± 3.47) and Noyyal river (5.53 ± 3.19), respectively (Table 5.1).

Of the 24 sampling locations, the highest number of species (34) was recorded from a forest stream (Site code: N_NCD) in Noyyal river with an average number of species of 10.25 ± 3.19 . River site (Site code: B_CP) in Bhavani river had a an average species of 9.25 ± 2.89 . The lowest recorded number of species was from a permanent tank (Site code: N_MUTH1) in Coimbatore city with nine species and an average of 3.91 ± 1.37 species. (Table 5.2).



**Figure 5.1 Species Accumulation Curve of a) observed species
b) predicted Species across different habitats**

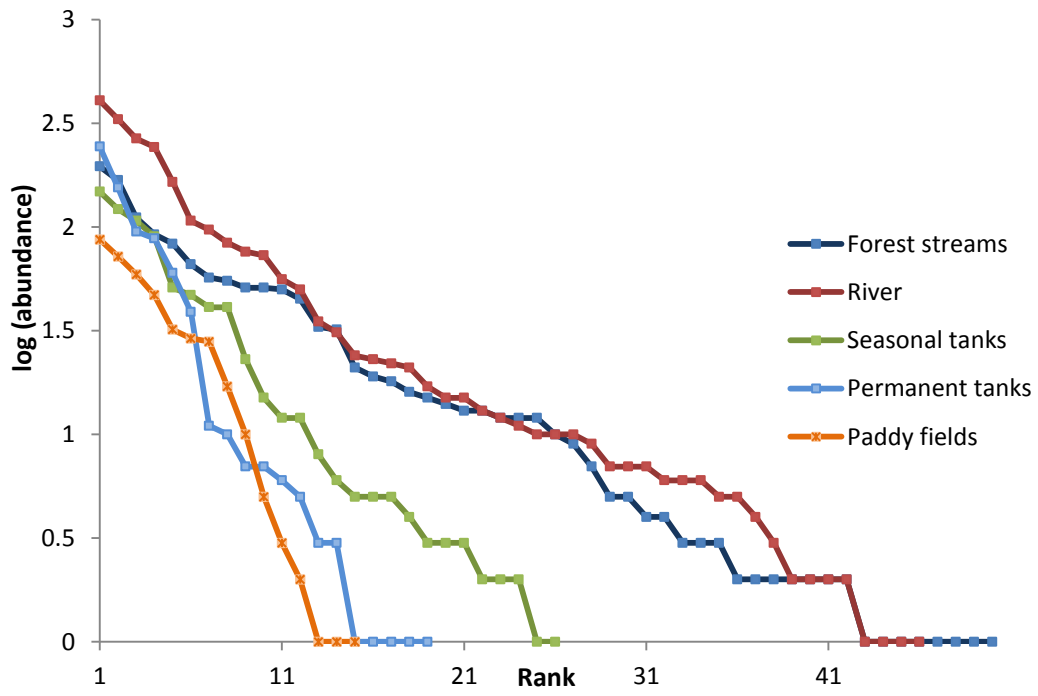


Figure 5.2. Rank abundance plot for the five aquatic habitats

Among the habitats, average abundance per study location was the highest in the river habitat (23.48±17.69), followed by forest streams (23.33±17.25). The lowest abundance were recorded from permanent tanks (15.37±12.98). There was no significant difference in mean abundance (ANOVA $F_{4,23} = 0.870$, $p = 0.5$) between the aquatic habitats. Of the rivers, Aliyar River had the highest mean abundance (23.97±19.05) (Table 5.1).

Of the sampling locations, species abundance was the highest in the Aliyar river site (A_ANM) with an average of 32.58 (±31.51) individuals, followed by the forest stream location (N_NCD) with an average abundance of 31.58(±17.14). Rank abundance curve for each of the habitats is presented in Figure 5.2. Forest streams had the longest curve, indicating more richness followed by river habitat. Similarly, these two habitats had lower slopes in the rank abundance curve, indicating low evenness. Rank abundance curves of seasonal tanks, permanent tanks and paddy fields had high slopes and shorter curves indicating high evenness and low richness.

From the diversity measures calculated, forest streams had the highest richness score across the diversity measures except evenness. Permanent tanks had the highest evenness measure score. Similarly, Noyyal River had the highest score of Shannon-Wiener, Simpson and Fisher's alpha and evenness was the highest in Aliyar River. The lowest diversity was recorded in permanent tanks among the habitat and among the rivers Aliyar River had the lowest diversity (Tables 5.1 and 5.2).

On comparing the relative abundance of species from different aquatic habitats (Figure 5.3), it was found that the most abundant species in forests streams were *Trithemis aurora* and *T. festiva*. The species *Pantala flavescens* was the most abundant species in river followed by *Trithemis aurora*. In seasonal tanks, *Crocothemis servilia* was the most abundant species. In permanent tanks *Brachythemis contaminata* and *Coeragrion coromandelianum* were the most abundant species. In paddy fields, *Pantala flavescens* and *Coeragrion coromandelianum* were the most abundant species.

5.3.2. BODY SIZE DISTRIBUTION

The total numbers of species recorded in the study sites (n=61), with different abdominal length and hindwing length classes are shown in (Figure 5.4). Frequency distribution of abdominal and hindwing length for all the habitats showed a unimodal mode of distribution.

Table 5.1 Species richness, abundance and diversity measures of aquatic habitats

Study Sites	Total Species richness	Mean Species richness (SD)	No. of Individuals	Mean abundance(SD)	Shannon-Weiner index	Simpson's index	Buzas and Gibson's Evenness measure	Fisher's alpha index
Overall	61	5.45 (1.56)	5523	19.25 (3.88)	3.069	0.933	0.352	9.596
Forest streams (n=5)	50	7.49 (3.73)	1330	23.33 (17.25)	3.076	0.932	0.433	10.260
River (n=9)	46	6.73 (3.21)	2302	23.48 (17.69)	2.817	0.908	0.363	8.145
Seasonal tank (n=4)	26	5.11(2.79)	759	17.65 (14.63)	2.468	0.885	0.454	5.213
Permanent tank (n=4)	19	3.56 (1.48)	738	15.37 (12.98)	1.942	0.805	0.367	3.558
Paddy fields (n=2)	15	4.83 (2.18)	394	16.41(10.53)	2.160	0.861	0.577	3.089
Noyyal river (n=14)	49	5.53 (3.19)	2944	19.11(14.69)	2.885	0.920	0.365	8.35
Bhavani river (n=6)	49	5.87 (3.47)	1428	21 (16.75)	2.809	0.903	0.338	9.82
Aliyar river (n=4)	38	7.14 (2.85)	1428	23.97 (19.05)	2.773	0.903	0.421	7.55

Table 5.2 Species richness, abundance and diversity measures of study locations.

Study Sites	Habitat	Total Species richness	Mean Species richness (SD)	No. of Individuals	Mean abundance(SD)	Shannon-Weiner index	Simpson's diversity index	Buzas and Gibson's Evenness measure	Fisher's alpha index
Bhavani river									
B_KALR	FS	18	6.1 (2.0)	247	20.5 (11.4)	2.22	0.85	0.51	4.4
B_BKL	R	14	3.5 (2.4)	168	14 (12.4)	1.96	0.80	0.50	3.6
B_VIL	R	16	3.5 (1.5)	196	16.3 (13.7)	2.14	0.84	0.53	4.1
B_CP	R	34	9.2 (2.8)	464	38.6 (18.0)	2.50	0.86	0.36	8.4
B_SAC	FS	25	6.0 (3.4)	226	18.8 (17.3)	2.54	0.88	0.50	7.1
B_KOND	FS	28	5.0 (5.2)	127	11.5 (15.4)	2.80	0.91	0.59	11.1
Noyyal river									
N_NCD	FS	34	10.25 (3.1)	379	31.5 (17.4)	2.96	0.93	0.57	9.0
N_SC	FS	28	8.5 (3.1)	351	29.2 (19.4)	2.55	0.89	0.45	7.1
N_MPTI	R	18	7.2 (1.3)	168	10.7 (11.0)	2.44	0.89	0.64	5.1
N_PER	R	15	5.1 (2.9)	155	36.0 (66.6)	1.95	0.79	0.47	4.1
N_PBS	P	13	5.2 (1.6)	202	16.8 (9.0)	2.03	0.83	0.58	3.1
N_WTL	P	11	4.7 (2.4)	192	16.0 (1.0)	1.99	0.81	0.66	2.5
N_VED1	ST	17	5.5 (3.6)	193	16.0 (17.2)	2.37	0.88	0.62	4.4
N_VED2	ST	19	4.2 (3.7)	165	13.7 (13.8)	2.43	0.87	0.59	5.5
N_MUTH1	PT	9	3.9 (1.3)	290	24.1 (14.8)	1.69	0.76	0.60	1.7
N_MUTH2	PT	13	3.9 (1.4)	223	18.5 (14.5)	1.59	0.68	0.37	3.0
N_KUR1	ST	17	5.0 (1.0)	199	16.5 (11.4)	2.22	0.85	0.54	4.4
N_KUR2	ST	16	3.6 (2.7)	202	16.8 (17.8)	2.08	0.84	0.50	4.0
N_SING1	PT	12	3.2 (1.6)	138	11.5 (9.5)	1.76	0.76	0.48	3.1
N_SING2	PT	13	3.1 (1.5)	87	7.2 (3.4)	1.89	0.77	0.51	4.2
Aliyar river									
A_ANM	R	24	6.0 (2.5)	391	32.5 (31.5)	1.89	0.72	0.27	5.6
A_AMB	R	21	7.4 (1.0)	299	24.9 (10.2)	2.47	0.87	0.56	5.1
A_ATP	R	30	8.2 (3.5)	239	19.9 (13.1)	2.77	0.91	0.53	9.0
A_KKP	R	22	6.9 (3.3)	222	18.5 (12.0)	2.89	0.85	0.47	6.0

The overall Odonate assemblage distribution based on size formed a sharp pointed triangle, indicating the presence of certain highly abundant species at the midrange sizes (Figure.5.4).

5.3.3. SIMILARITY OF ASSEMBLAGES BETWEEN HABITATS

The NMDS ordination based on Bray-Curtis similarity measure (stress=0.14) demonstrated a clear distinction in Odonate assemblages between all five aquatic habitats (Figure 5.5). The NMDS ordination based on Jaccard index (stress=0.14) showed an overlap in river, seasonal and permanent tank locations, yet there was an overall distinction in Odonate assemblages in both the ordinations. ANOSIM calculated using Bray-curtis index showed that Odonate composition significantly different between the aquatic habitats (Global R=0.592, $p < 0.0001$). Forest streams differed in composition with all other aquatic habitats (Table 5.3). River habitat also differed in Odonate composition with other habitats. Seasonal tanks showed similarity in composition with permanent tanks and paddy fields. Paddy fields did not show any significant difference in similarity with seasonal and permanent tanks.

From the analysis obtained from SIMPER (Similarity Percentage) (Table 5.4), *Pantala flavescens* and *Brachythemis contaminata*, were the highest contributing species in the dissimilarity in composition between forest and river habitats. *Brachythemis contaminata* was the highest contributing species towards the dissimilarity between river and permanent tanks. *Trithemis aurora*, *Pantala flavescens* and *Crocothemis servila* were the highly contributing species over the dissimilarity between river and permanent tanks, river and paddy fields. *Trithemis festiva* was the highest contributing species in the dissimilarity to the assemblages in river and seasonal tanks. Between forest streams and seasonal tanks, *Trithemis festiva* and *T. aurora* were the highest contributing species. Similarly, between forest streams and permanent tanks, *Trithemis festiva* and *Brachythemis contaminata* were the highest contributing species for their dissimilarity in composition.

5.3.4. SIMILARITY BETWEEN STUDY LOCALITIES

Similarity in composition across locations was estimated based on incidence (Jaccard) and abundance (Bray-Curtis) based similarity measures (Table 5.5). Lotic water sites such as forest streams and rivers were less similar with lentic water sites. The lentic water sites which include, seasonal tanks, permanent tanks and paddy fields were more similar to each other. Both incidence and abundance based distance measures showed almost a similar pattern of pairwise comparisons between locations.

Table 5.3. Analysis of similarity (ANOSIM) between five aquatic habitats.

Group I	Group II	R value	p value
Forest streams	River	0.311	0.015
Forest streams	Seasonal tank	0.987	0.009
Forest streams	Permanent tank	1.000	0.008
Forest streams	Paddy field	0.981	0.049
River	Seasonal tank	0.481	0.002
River	Permanent tank	0.587	0.001
River	Paddy field	0.642	0.017
Seasonal tank	Permanent tank	0.250	0.115
Seasonal tank	Paddy field	0.892	0.066
Permanent tank	Paddy field	0.785	0.070

(Significant values are presented in bold $p < 0.05$)

Table 5.4 The top five species significantly influencing the dissimilarity between the groups obtained through SIMPER (Similarity Percentage).

Group I	Group II	Species
Forest streams	River	<i>Pantala flavescens</i> (11.6) <i>Brachythemis contaminata</i> (8.5) <i>Trithemis festiva</i> (8.2) <i>Pseudagrion rubriceps</i> (6.9) <i>Trithemis arora</i> (6.7)
Forest streams	Seasonal tank	<i>Trithemis aurora</i> (11.24) <i>Trithemis festiva</i> (9.2) <i>Crocothemis servilia</i> (7.9) <i>Brachythemis contaminata</i> (7.1) <i>Pantala flavescens</i> (6.8)
Forest streams	Permanent tank	<i>Brachythemis contaminata</i> (15.7) <i>Trithemis aurora</i> (10.97) <i>Trithemis festiva</i> (9.1) <i>Ceriagrion coromandelianum</i> (8.7) <i>Pseudagrion rubriceps</i> (6.3)
Forest streams	Paddy field	<i>Trithemis aurora</i> (11.0) <i>Pantala flavescens</i> (10.2) <i>Ceriagrion coromandelianum</i> (9.7) <i>Trithemis festiva</i> (9.2) <i>Orthetrum pruinosum</i> (5.8)
River	Seasonal tank	<i>Trithemis festiva</i> (11.8) <i>Crocothemis servilia</i> (9.9) <i>Pantala flavescens</i> (9.7) <i>Brachythemis contaminata</i> (9.5) <i>Pseudagrion rubriceps</i> (8.5)
River	Permanent tank	<i>Brachythemis contaminata</i> (13.7) <i>Trithemis aurora</i> (11.3) <i>Pantala flavescens</i> (10.6) <i>Ceriagrion coromandelianum</i> (9.6) <i>Pseudagrion rubriceps</i> (8.5)
River	Paddy field	<i>Trithemis aurora</i> (10.8) <i>Ceriagrion coromandelianum</i> (10.3) <i>Pantala flavescens</i> (10.0) <i>Pseudagrion rubriceps</i> (8.1) <i>Brachythemis contaminate</i> (7.6)

Table 5.5 Comparison of study locations by Similarity index: Jaccard (lower left) and Bray-Curtis (upper right)

	A_ANM	A_AMB	A_ATP	A_KKP	B_SAC	B_KOND	B_CP	B_BKL	B_VIL	B_KALR	N_SC	N_NCD	N_MPTI	N_PER	N_VED1	N_VED2	N_PBS	N_WTL	N_MUTH1	N_MUTH2	N_KUR1	N_KUR2	N_SING1	N_SING2	
Lentic waterbodies	A_ANM		0.5	0.7	0.6	0.5	0.4	0.5	0.5	0.6	0.3	0.4	0.5	0.5	0.6	0.5	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.4	0.4
	A_AMB	0.5		0.5	0.5	0.5	0.4	0.7	0.5	0.5	0.5	0.6	0.4	0.5	0.4	0.3	0.3	0.2	0.2	0.3	0.2	0.3	0.2	0.2	0.3
	A_ATP	0.7	0.4		0.7	0.5	0.5	0.6	0.5	0.6	0.3	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.6	0.6	0.5	0.5
	A_KKP	0.5	0.4	0.7		0.5	0.4	0.6	0.5	0.5	0.3	0.5	0.5	0.5	0.6	0.5	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.4
	B_SAC	0.5	0.4	0.5	0.4		0.6	0.6	0.5	0.6	0.5	0.6	0.5	0.6	0.5	0.3	0.4	0.4	0.4	0.3	0.4	0.5	0.3	0.3	0.3
	B_KOND	0.4	0.3	0.5	0.4	0.4		0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.4	0.4	0.5	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3
	B_CP	0.5	0.5	0.5	0.5	0.5	0.4		0.6	0.5	0.5	0.7	0.5	0.6	0.5	0.4	0.4	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.3
	B_BKL	0.4	0.4	0.3	0.4	0.4	0.4	0.4		0.7	0.5	0.6	0.4	0.6	0.5	0.3	0.3	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3
	B_VIL	0.5	0.5	0.4	0.4	0.6	0.3	0.3	0.5		0.5	0.6	0.5	0.7	0.6	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4
	B_KALR	0.4	0.5	0.3	0.3	0.4	0.4	0.4	0.4	0.5		0.7	0.4	0.5	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	N_SC	0.4	0.5	0.5	0.4	0.5	0.5	0.6	0.4	0.4	0.5		0.5	0.6	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	N_NCD	0.5	0.3	0.5	0.4	0.4	0.5	0.4	0.3	0.4	0.3	0.5		0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4
	N_MPTI	0.5	0.4	0.5	0.4	0.5	0.4	0.5	0.4	0.6	0.4	0.5	0.4		0.6	0.5	0.5	0.4	0.5	0.4	0.4	0.5	0.4	0.5	0.5
	N_PER	0.4	0.3	0.5	0.5	0.3	0.3	0.4	0.3	0.5	0.3	0.3	0.4	0.5		0.6	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.6
Lentic waterbodies	N_VED1	0.4	0.2	0.5	0.4	0.3	0.3	0.3	0.3	0.1	0.3	0.5	0.3	0.5		0.8	0.6	0.6	0.7	0.6	0.7	0.7	0.6	0.6	
	N_VED2	0.4	0.2	0.4	0.4	0.3	0.4	0.3	0.3	0.2	0.3	0.4	0.4	0.4	0.6		0.5	0.6	0.5	0.5	0.6	0.6	0.5	0.5	
	N_PBS	0.3	0.2	0.4	0.3	0.3	0.2	0.2	0.2	0.3	0.1	0.2	0.3	0.3	0.4	0.4	0.3		0.8	0.6	0.6	0.7	0.6	0.6	0.5
	N_WTL	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.2	0.3	0.3	0.5	0.4	0.5	0.4	0.6		0.7	0.6	0.7	0.6	0.6	0.6
	N_MUTH1	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.3	0.4	0.3	0.6	0.5		0.7	0.7	0.7	0.7	0.7
	N_MUTH2	0.3	0.2	0.4	0.4	0.3	0.2	0.3	0.3	0.3	0.1	0.4	0.3	0.3	0.5	0.6	0.4	0.5	0.5	0.5		0.7	0.7	0.6	0.7
	N_KUR1	0.4	0.2	0.5	0.4	0.4	0.3	0.3	0.2	0.3	0.2	0.3	0.3	0.4	0.4	0.5	0.4	0.6	0.6	0.4	0.5		0.8	0.7	0.7
	N_KUR2	0.4	0.2	0.5	0.4	0.3	0.3	0.3	0.2	0.3	0.1	0.3	0.4	0.3	0.5	0.7	0.6	0.4	0.4	0.4	0.6	0.7		0.7	0.7
	N_SING1	0.3	0.2	0.4	0.4	0.3	0.2	0.2	0.3	0.4	0.2	0.3	0.2	0.3	0.4	0.5	0.3	0.6	0.5	0.6	0.5	0.5	0.5		0.7
	N_SING2	0.3	0.2	0.4	0.3	0.3	0.3	0.2	0.3	0.3	0.2	0.3	0.4	0.3	0.5	0.6	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.6	

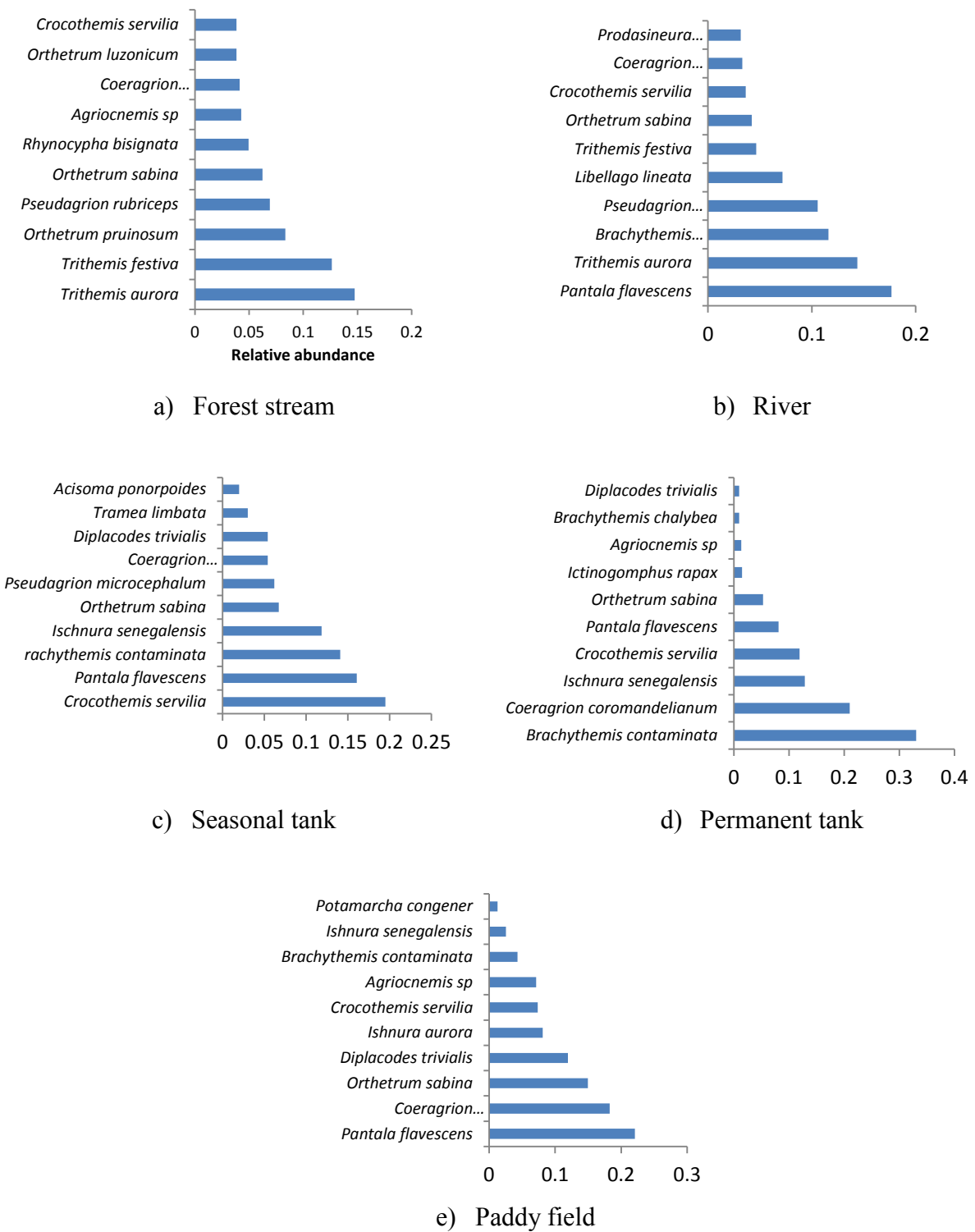
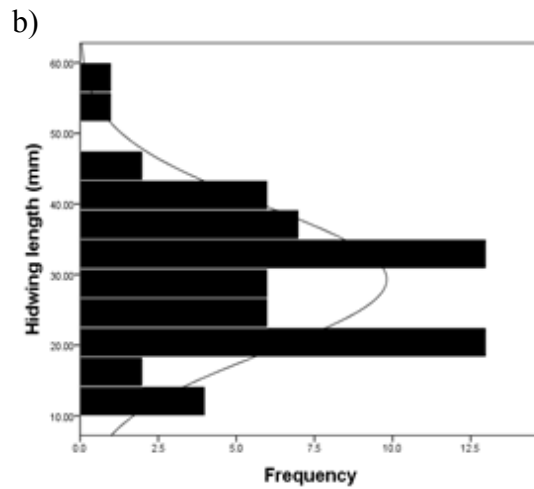
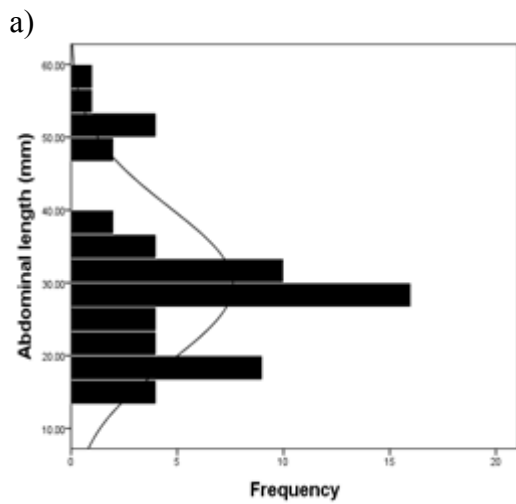
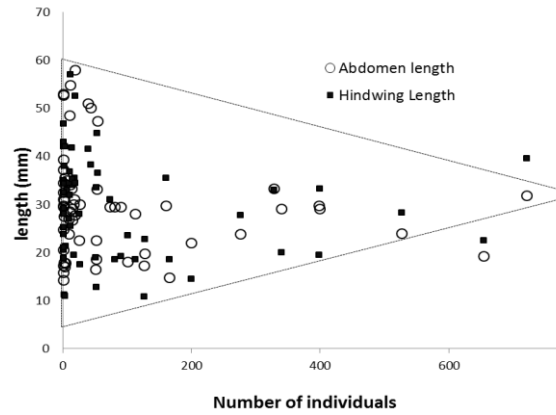
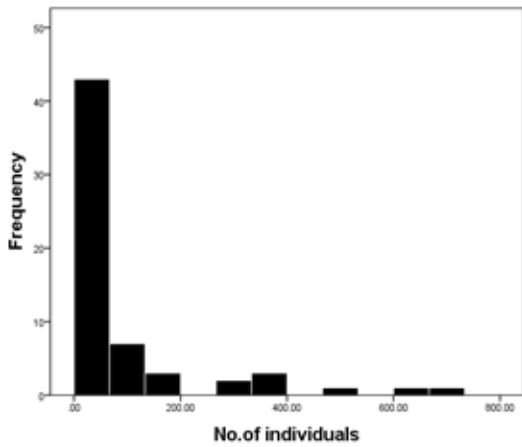


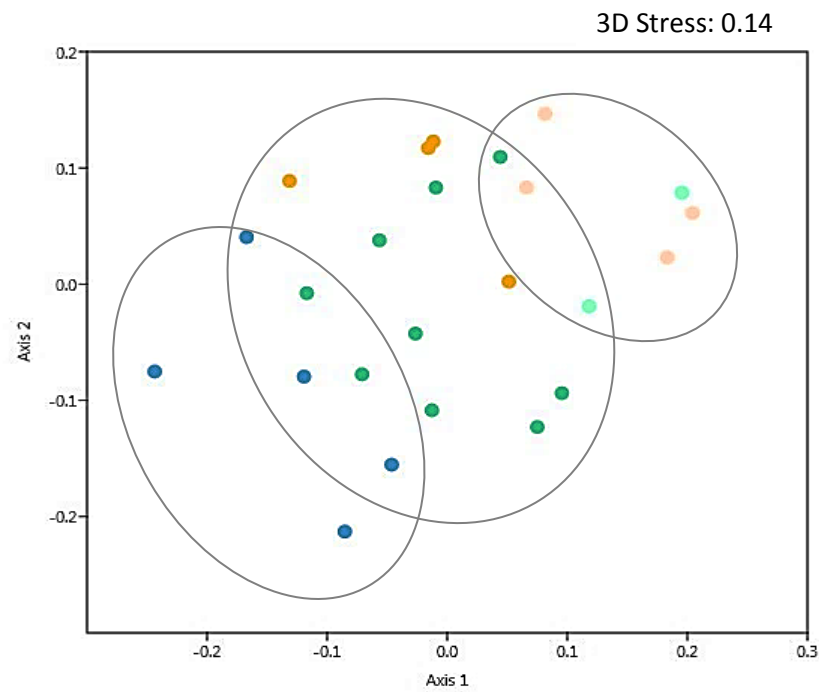
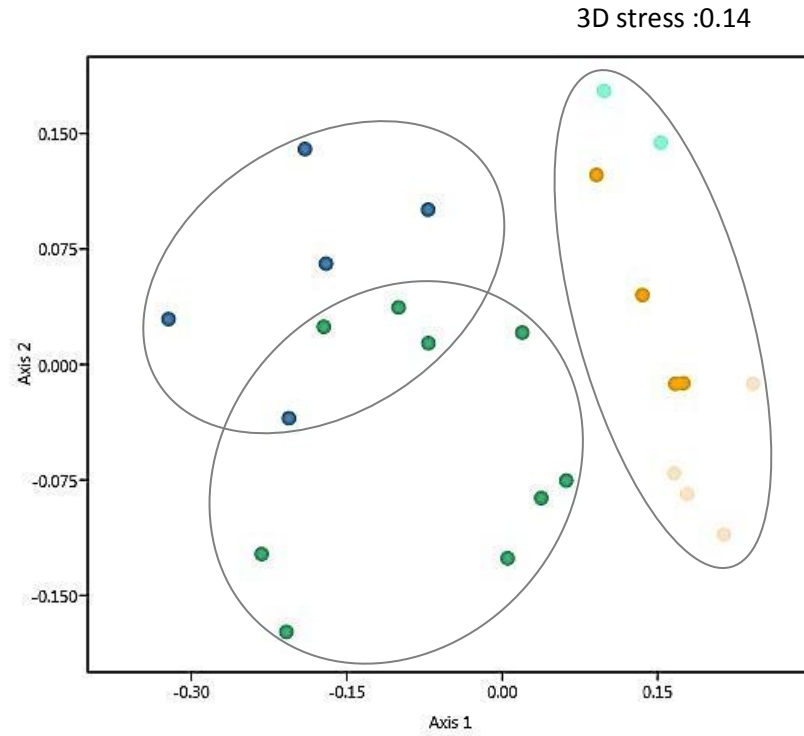
Figure 5.3. Relative abundance of top ten Odonate species from each aquatic habitat



c)

d)

Figure 5.4) a) Frequency distribution of overall Odonates b) Number of individuals against the abdominal and hindwing length c) Frequency distribution of abdominal length and d) Frequency distribution of hind wing length



● Forest stream ● River ● Seasonal tank ● Permanent tank ● Paddy field

Figure 5.5. Three dimensional NMDS plot of aquatic habitats based on Odonate composition. a) Using Bray-Curtis similarity b) Jaccard index

5.3.5. SEASONAL VARIATION IN RICHNESS AND ABUNDANCE

The northeast monsoon months of October and November had the highest mean species richness per season (15.8 ± 6.1) and abundance (45 ± 28.1). Likewise, the lowest species richness (11.8 ± 7.7) and abundance (31.2 ± 24.14) were observed during the month of February and March. However, there was no significant difference in species richness (ANOVA $F_{5,115} = 2.06$, $p = 0.07$) and abundance (ANOVA $F_{5,115} = 1.37$, $p = 0.36$) between the seasons.

In general, in the first year of study, in all aquatic habitats species richness and abundance were the lowest in the months of December-January and February-March (early summer) and gradually increased over the following months and peaked in October-November (Figure 5.6 and 5.7). However, in the second year of study, the richness and abundance of Odonates in the months of February-March was high when compared with the first year of study.

Nearly 20% of the total Odonate abundance was represented in the months of October-November and only 13% was represented in the months of February-March. *Pantala flavescens* showed the highest abundance during the months of August-September and October-November (Table 5.6). *Orthetrum sabina* (December-January), *Pseudagrion rubriceps* (February-March), *Ceriagrion coromandelianum* (April-May), *Trithemis aurora* (June-July) were the most abundant species in the respective months.

5.3.6. SEASONAL VARIATION IN ODONATE ASSEMBLAGES

ANOSIM test revealed that the assemblages significantly varied between the seasons (Global $R = 0.04$, $p = 0.004$). Pairwise comparison of seasons indicated that species composition in the winter months of December-January was similar with the months February-March ($R = -0.01$, $p > 0.05$) and significantly varied with all other seasons. The species composition in the month February-March varied significantly with the monsoonal months of August-September ($R = 0.05$; $p = 0.0357$) and October-November ($R = 0.064$; $p = 0.0265$) (Table 5.7).

To identify if the same pattern was observed individually in both study years, ANOSIM was performed (Global $R = 0.03$, $p = 0.002$). In the first year of study (August, 2013-July, 2014), the Odonate composition in the month of December-January was similar to February-March and April-May ($p > 0.05$) and dissimilar with all other months. August-

Table 5.6. Relative abundance of top five species in different seasons

Seasons	Species
December-January (Winter) (15% of total abundance)	<i>Orthetrum sabina</i> (11.5%) <i>Pseudagrion rubriceps</i> (8.7%) <i>Ceriagrion coromandelianum</i> (7.5%) <i>Agriocnemis sp</i> (6.7%) <i>Trithemis aurora</i> (6.4%)
February-March (Presummer) (13.6% of total abundance)	<i>Pseudagrion rubriceps</i> (14.8%) <i>Trithemis aurora</i> (11.6%) <i>Orthetrum sabina</i> (9.6%) <i>Ceriagrion coromandelianum</i> (7.6%) <i>Ischnura senegalensis</i> (7.3%)
April-May (Summer) (17.6% of total abundance)	<i>Ceriagrion coromandelianum</i> (12.7%) <i>Trithemis aurora</i> (10.6%) <i>Brachythemis contaminata</i> (10%) <i>Ceriagrion coromandelianum</i> (8.7%) <i>Crocothemis servilia</i> (9.8%) <i>Libellago lineata</i> (5.7%)
June-July (Southwest Monsoon) (16.6% of total abundance)	<i>Trithemis aurora</i> (14.3%) <i>Brachythemis contaminata</i> (11.9%) <i>Ceriagrion coromandelianum</i> (9.6%) <i>Crocothemis servilia</i> (8.8%) <i>Trithemis festiva</i> (6.8%)
August-September (Late Southwest Monsoon) (17.5% of total abundance)	<i>Pantala flavescens</i> (23.2%) <i>Brachythemis contaminata</i> (22.7%) <i>Trithemis aurora</i> (9.6%) <i>Crocothemis servilia</i> (6.7%) <i>Trithemis festiva</i> (4%)
October-November (Northeast Monsoon) (19.8% of total abundance)	<i>Pantala flavescens</i> (28.5%) <i>Brachythemis contaminata</i> (11.0%) <i>Crocothemis servilia</i> (11.34) <i>Trithemis aurora</i> (5.3%) <i>Pseudagrion rubriceps</i> (5.1%)

Table 5.7. ANOSIM analysis for differences in species composition between seasons (significance value (p) and R values are provided)

Overall Seasons						
	Apr-May	Aug-Sep	Dec-Jan	Feb-Mar	Jun-July	Oct-Nov
Apr-May	.					
Aug-Sep	0.119 0.033	.				
Dec-Jan	0.030 0.065	0.002 0.133	.			
Feb-Mar	0.359 0.005	0.022 0.073	0.651 -0.014	.		
Jun-July	0.729 -0.019	0.347 0.004	0.012 0.093	0.148 0.029	.	
Oct-Nov	0.072 0.046	0.354 0.005	0.016 0.083	0.027 0.722	0.090 0.044	.
August, 2013 - July, 2014						
	Apr-May	Aug-Sep	Dec-Jan	Feb-Mar	Jun-July	Oct-Nov
Apr-May	.					
Aug-Sep	0.091 0.040	.				
Dec-Jan	0.044 0.061	0.0001 0.199	.			
Feb-Mar	0.573 -0.009	0.007 0.099	0.321 0.011	.		
Jun-July	0.660 -0.016	0.162 0.027	0.037 0.067	0.123 0.036	.	
Oct-Nov	0.038 0.064	0.288 0.011	0.027 0.077	0.009 0.103	0.079 0.046	.
August, 2014 - July, 2015						
	Apr-May	Aug-Sep	Dec-Jan	Feb-Mar	Jun-July	Oct-Nov
Apr-May	.					
Aug-Sep	0.493 -0.004	.				
Dec-Jan	0.043 0.058	0.006 0.105	.			
Feb-Mar	0.309 0.009	0.104 0.040	0.509 -0.004	.		
Jun-July	0.649 -0.014	0.788 -0.024	0.040 0.061	0.1959 0.023	.	
Oct-Nov	0.703 -0.017	0.518 -0.005	0.169 0.024	0.4587 -0.001	0.473 -0.002	.

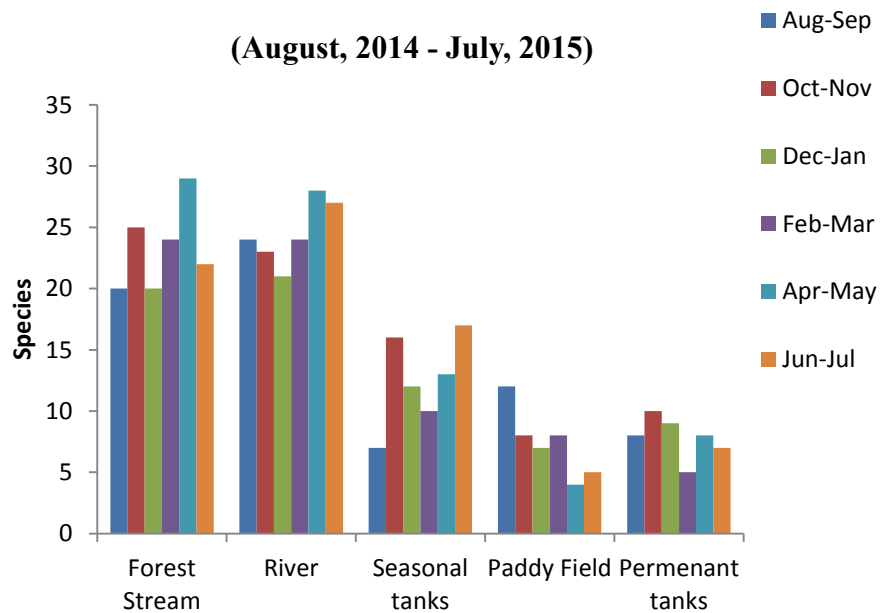
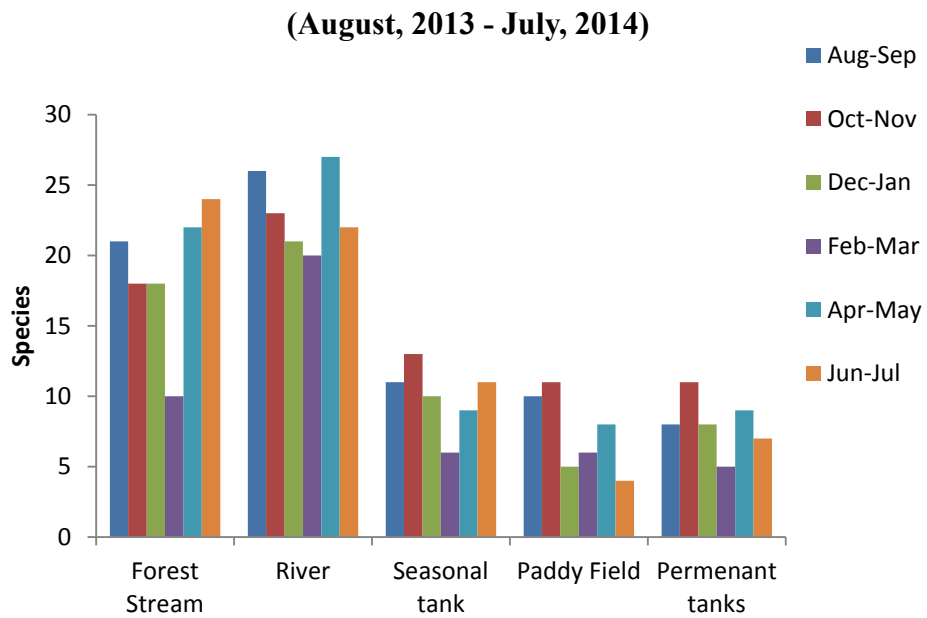


Figure 5.6. Species richness of Odonates from different aquatic habitats from all seasons in both years of study.

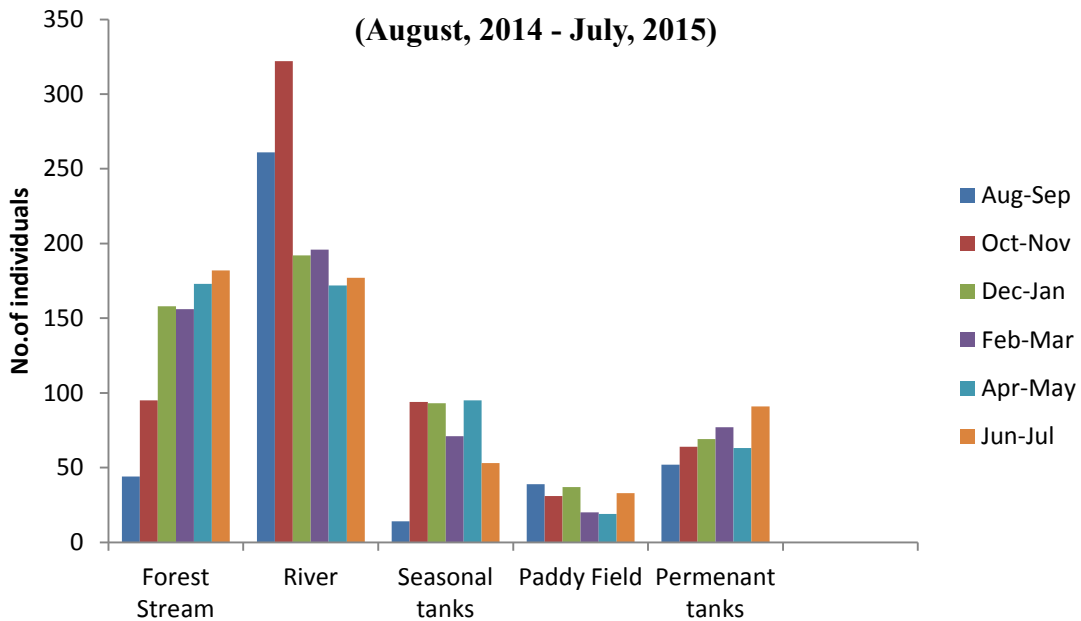
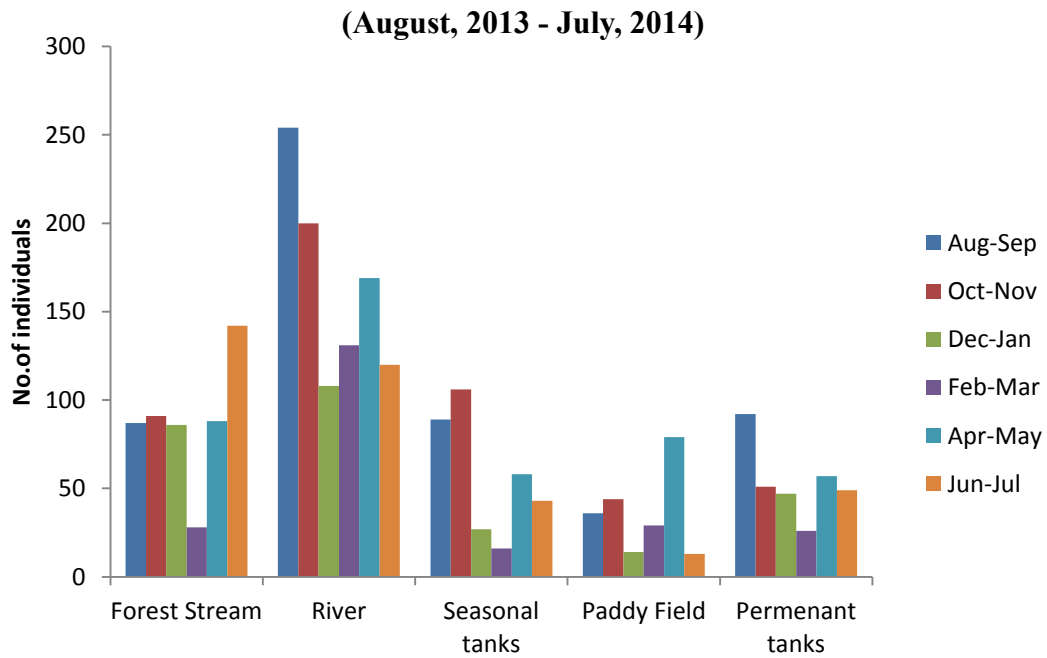


Figure 5.7. Species abundance of Odonates from different aquatic habitats from all seasons in both years of study.

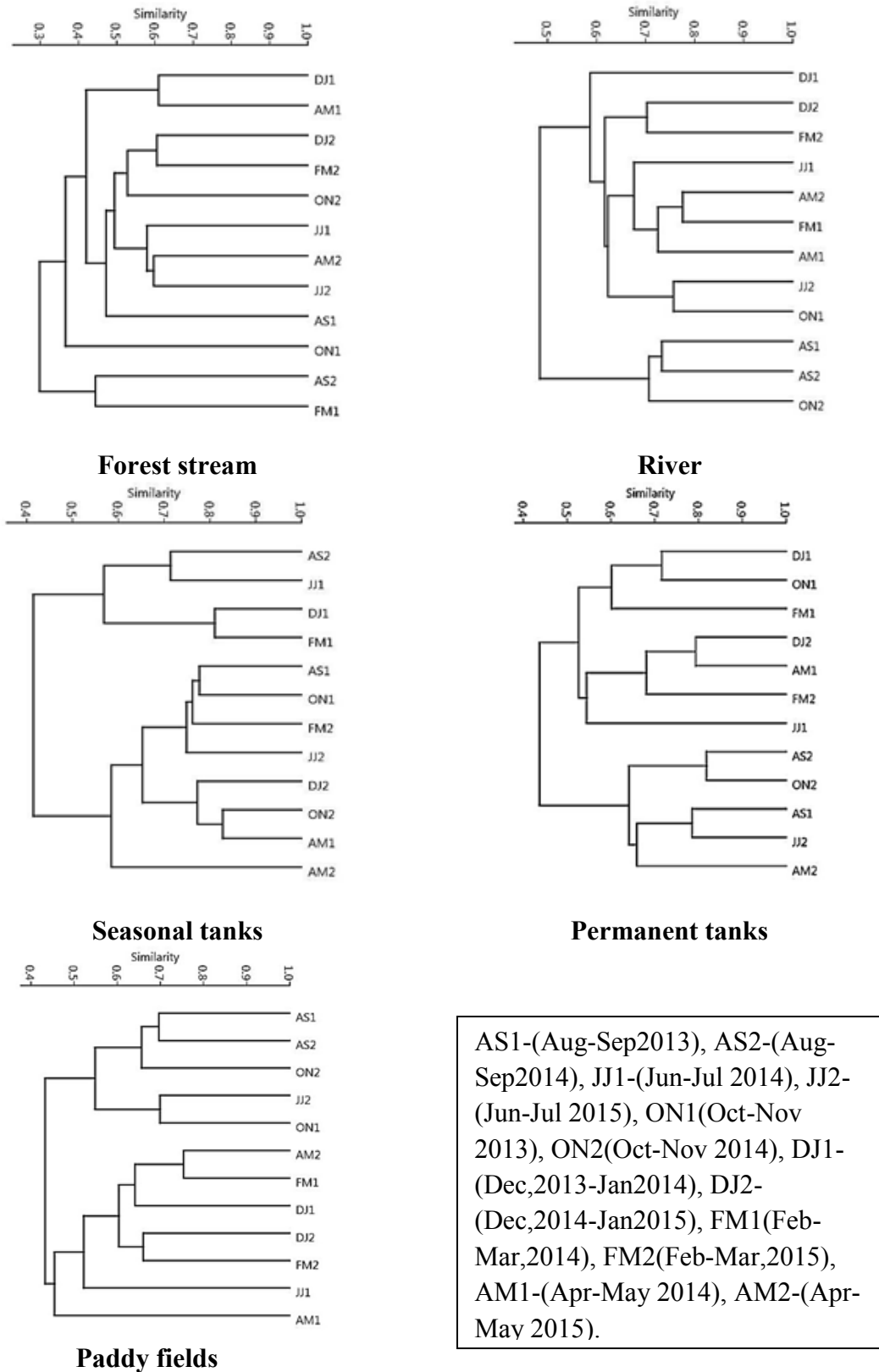


Figure 5.8. Cluster analysis of seasons in different aquatic habitats.

September significantly varied in composition with December-January ($R=0.09$, $p=0.01$) and February-March ($R=0.07$, $p=0.02$) and was similar with the other seasons. In the second year (August, 2014-July, 2015), December-January had a similar composition with October-November ($R=0.02$, $p>0.05$) and February-March ($R=0.00$, $p>0.05$). December-January varied in Odonate composition with April-May ($R=0.05$, $p=0.04$), June-July ($R=0.06$, $p=0.04$) and August-September ($R=0.1$; $p=0.001$). (Table 5.7)

In the cluster analyses of seasons in forest stream Odonate communities (Figure 5.8), all seasons were clustered together, except for the winter (December 2013- January 2014), pre summer (February-March 2014), summer (April-May 2014), and post southwest monsoon (August-September 2014). In river, post southwest monsoon months of August-September in both years of 2013 and 2014 and northeast monsoon (October-November 2014) had similar composition of Odonates. All other seasons, except (December 2013- January 2014), were clustered together. In seasonal tanks, winter (December 2013-January 2014) and pre-summer (February-March 2014) had similar Odonate assemblage and southwest monsoon (June-July, 2014) and late Southwest monsoon (August-September, 2014) were similar. All other seasons clustered together indicating the similarity in composition. In Paddy fields Odonate communities were clustered based on monsoonal months (June to November) and non-monsoon months (December to May). Permanent tanks did not show any clear pattern of clustering (Figure 5.8).

5.4. DISCUSSION

Almost one third of all the species recorded were represented in all the habitats. These species were high in abundance accounting for nearly 80% of total encounters. There was variation in richness and abundance across aquatic habitats. Low richness and high evenness in lentic water habitats were observed. Lentic water species are known to be generalist with high dispersal ability (Corbet, 1999). Highest diversity was observed in forest stream and river habitats. Studies have indicated that high diversity of Odonates is known to be restricted to forest habitats (Paulson, 2006). Forest species also hold more endemic species than other modified habitats (Oppel 2005, 2006b; Samways and Sharratt, 2009). High diversity in forest stream sites could be attributed to the varied microhabitats available for space utilisation Orr (2001). Species richness and abundance tends to be high in riverine areas in the present study and this is in accordance with earlier studies (Horwitz, 1978; Illies and Botosaneanu, 1963) which showed that larger rivers harbour greater habitat diversity due to their more extensive

habitat area. Studies on other macroinvertebrates have indicated that richness of ponds depends on their proximity to river or forest streams and when they are deprived of freshwater sources have low diversity (Williams *et al.* 1996). This is evident in the present study where seasonal tanks which are drained by river water are species rich when compared to permanent tanks. Permanent tanks in the study are prone to multiple levels of pollution through drain and sewage inlets from the city. Also, Odonates in seasonal and permanent tanks are influenced by species characteristics, such as their flight activity and their ability to emerge rapidly as adults (McCauley, 2006).

Even in the absence of human induced modifications, species are not fixed entities and are prone to undergo natural turnovers based on species presence and absence. Hence, alpha diversity alone may not provide full information on the changes in community structure and also the impacts of human-made interferences (Magurran, 2016). Species richness alone can often mislead information on the status of habitats. This has been indicated from many studies, in disturbed forests, species richness increased by the inclusion of generalist species to the species pool (Dijkstra and Lempert, 2003), and species composition varied but species richness did not vary (Dolný *et al.* 2012).

Beta diversity analyses are essential to understand the community heterogeneity of Odonates for assessing habitat quality. In this study, aquatic habitats were segregated based on the composition of Odonates. All lentic water habitats tended to have similar composition. Forest and river habitats varied in assemblage with lentic habitats such as seasonal tanks, permanent tanks and paddy fields. The habitat specific distribution of Odonates based on lentic and lotic systems has been reported (Hof *et al.* 2006; Hardersen, 2008; Hart *et al.* 2014). The range sizes of lentic and lotic Odonates have been found to be different (Hof *et al.* 2006). Lentic species have more general species and high dispersal ability (Corbet, 1999) and lotic species on the other hand are found to be at greater risk, due to their inability to disperse over a wide range of habitats (Clausnitzer *et al.* 2009). In this study the disparity in composition between forests streams and river could be attributed to the vegetation structure, and the fact that river systems support numerous microhabitats for generalist species (Williams *et al.* 2003). From this study it was found that although the longer hydroperiod water bodies contributed to higher species diversity, seasonal streams in the forested areas also tend to have high species diversity. This indicates the fact that habitat structures influence Odonate diversity as much as hydroperiod (Dijkstra and Lempert, 2003). Flow rate and hydroperiod of water are considered as the most important factor influencing Oodnate

assemblages and habitat structure also known to greatly determine Odonate community structure (McPeck, 2008). Riparian study locations such as the downstream of the Bhavani River have lower species when compared to upstream locations possibly due to the effect of damming. The downstream and upstream Odonate species composition varied. Damming can affect downstream assemblages due to alteration in flow and sedimentation patterns (Suhling *et al.* 2003)

The rainfall pattern in Coimbatore district varies, due to which the permanence of water also varies in different aquatic bodies. Seasonal changes in species composition across different water bodies showed that species composition in the summer, southwest monsoon and northeast monsoon were not significantly different. However the pre-summer months of February and March and the winter months of December and January had significant difference in species composition compared to all other seasons. This could be due to the fact that, Coimbatore experiences dry period in the months of February and March. It receives summer showers occasionally in the months of April and May which continues with the Southwest monsoon period. Species compositions between seasons were generally similar during wet period and differed with dry periods of December-January and February-March. The results largely agree with the findings of Legrand and Couturier (1985), seasonally Odonate abundance and richness subsides during the pre-summer, during which many of the temporary ponds and streams are dry. During summer, Studies showed that, eggs tend to go into diapause during harsh conditions and larvae either emerge out before drying up of the pond or perish (Williams, 1996). There is high abundance and richness during both the southwest monsoon (June-September) and northeast monsoon (October-November). Odonates in India, are most abundant during this period (Subramanian, 2009). The difference in species composition in the months between the study years could be attributed to the drought period of early 2013, during which some of the forest streams remained dry. Also, certain species such as *Pantala flavescens* are migratory in nature (Buden, 2010) and emerge in huge swarms during the months of August-November (Fraser, 1936; Anderson, 2009). In Micronesia, this species is known to emerge in large swarms in the months of August and September (Buden, 2010).

While richness and diversity affects Odonate distribution, traits such as body size and wing patterns also greatly influence species composition in each location. The dragonfly's size distribution pattern in Coimbatore falls under a unimodal pattern, in accordance with the study of Hutchinson and MacArthur (1959), where they found that in a taxon, there are more

intermediate size species than very large or very small ones. Also larger species tend to be lesser in abundance, such as the Gomphids and Aeshnids, where being the largest individuals; they tend to be in solitary in locations and are highly territorial. Similar pattern was observed by van Valen (1973), Kochmer and Wagner (1988) in birds. Body sizes influence niche partitioning by competitive abilities (Worthen and Jones, 2007). Wing shape of Odonata reflects habitat use, mate guarding behaviour and migratory ability (Johansson *et al.* 2009). Broader wings are found in species that frequent open habitats. The hind wing shape is significantly related to both landscape type and wing colouration. *Pantala flavescence* has large asymmetric size advantage in larval development over other resident species. They oviposit earlier and are larger in a given instant compared to the larval stages of other residents. They are most abundant during mid and late summers when most of the residents are much smaller. Life history characteristics such as phenology, synchrony and voltinism influence the intra and inter specific size combination of species determining the population structure of a region (Wissinger, 1988).

5.5. CONCLUSION

To summarize, there was variability in richness, abundance and composition between aquatic habitats in Coimbatore district. Diversity was highest in forest streams and river systems and lowest in permanent tanks. Of the rivers Noyyal River was the most diverse. Beta diversity analyses revealed significant differences in composition between the aquatic habitats. While all lentic systems such as seasonal tanks, permanent tanks and paddy fields were similar in composition, forest streams and river varied in composition with the rest. Comparison between study locations also indicated that habitat conditions mattered more on the similarity between locations. While, species richness and abundance did not vary much with the seasons, species composition varied greatly between seasons.

CHAPTER 6

FACTORS INFLUENCING ODONATE COMMUNITY COMPOSITION

6.1 INTRODUCTION

Biological traits of organisms determine the range size of a species and habitat qualities provide a physical framework which constrains ecological and evolutionary strategies of species (Gaston, 1997). The establishment of dedicated distribution-mapping schemes and the use of modern tools to measure vegetation and other environmental variables has resulted in the identification of factors influencing the composition of different species (Gaston, 2000). Ecological factors influencing Odonate assemblages and diversity has remained as the subject of study over long period, as these factors determine the process of speciation, extinction and migration of species (Crumrine *et al.* 2008).

The presence or absence of an Odonate species in a given area, is influenced by a wide range of physicochemical, biological and spatial factors (Corbet, 1999). The sensitivity of Odonates to abiotic and biotic factors makes them good indicators of aquatic habitats (Dijkstra and Lempert, 2003; Opperl, 2005; Samways and Sharratt, 2009; Simaika and Samways, 2012). Some of the major ecological factors influencing the distribution and composition of Odonates in freshwater systems include structure of the habitats (Samways and Sharratt, 2009), physicochemical parameters (Kietzka *et al.* 2016) nature of vegetation (Buchwald, 1992), presence of predators such as fish (Stoks *et al.* 2003) and flow rate of water (Dijkstra and Lempert, 2003). While most studies on habitat association are from the temperate regions of the world, a few studies on the habitat association of Odonate species in the tropical region are mostly from the Afro-tropical region (Dijkstra and Clausnitzer, 2006; Grant and Samways, 2007; Clausnitzer *et al.* 2012; Kietzka *et al.* 2015; Simaika and Samways, 2012; Stewart and Samways, 1998; Suhling *et al.* 2009), neo-tropical (Paulson, 2006) and Oriental in Papua New Guinea (Opperl, 2005, 2006a, 2006b) Indo-Malayan peninsula and Borneo (Orr, 2004). Studies on ecological factors influencing Odonate distribution and composition in the Indian scenario are limited (Subramanian *et al.* 2008, Das *et al.* 2013, Koparde *et al.* 2015). In the present study, an attempt has been made to address the effect of ecological factors *viz.* vegetation cover, precipitation,

temperature, physicochemical parameters, permanence and flow of water on Odonate assemblages.

6.2 THE DATA

Environmental variables

A total of 18 environmental variables (Table 6.1) were recorded on each sampling date. Measurement of water variables namely., water temperature in °C, pH, electrical conductivity (EC) in $\mu\text{S}/\text{cm}$, was measured using a hand held water probe (EUTECH-Multi-purpose meter). The data on weather parameters namely., maximum and minimum temperature in °C, rainfall in mm and relative humidity in %, for each sampling unit were obtained from Agro-Climatic Research Centre (ACRC) of Tamil Nadu Agricultural University (TNAU) based on the recordings of the nearest Automatic Weather Station (AWS) to the study site. The flow rate of water were categorised as stagnant, gliding, rapid and dry. The flow rate variables were considered as categorical variable. The rest of the variables were based on the observations made in the field in the form of percentages: native and invasive shrubs, aquatic macrophyte cover (other than water hyacinth), water hyacinth cover, surface rocks, sandbanks cover, grass reeds and tree cover was represented as shade percentage.

6.3. DATA ANALYSES

Statistical analyses followed in this chapter, is based on the methods followed by Kietzka *et al.* (2016). The influence of environmental variables on species richness was assessed by Generalised Linear Mixed Model (GLMM) with Poisson distribution (log-link function). The GLMM analysis was carried out for overall Odonate, Anisoptera and Zygoptera species richness. Canonical Correspondence Analysis (CCA) was used to correlate species composition with environmental variables. The constrained analysis was carried out to estimate the simple effect of each variable. Since this analysis could involve type III error resulting in false positive relation of variables with Odonate assemblage interactive forward selection analyses (ter Braak, 1990) was used to select the most critical environmental variable influencing the Odonate assemblage. To identify the environmental variables with non-significant collinearity with Odonate assemblages, the Variance Inflation Factor (VIF) with a

Table. 6.1. Effects of environmental variables on combined species richness (Overall, Anisoptera and Zygoptera)

Variables	Overall	Anisoptera	Zygoptera
Weather parameters			
Temperature (maximum)	1.20	0.65	-0.19
Relative humidity	1.86	2.01*	-1.17
Rainfall	0.24	0.06	0.29
Wind speed	0.92	2.70**	-0.86
Water measures			
Water temperature	3.32**	2.90**	1.54
pH	-0.31	-0.53	0.05
Conductivity	-1.24	-2.11*	0.69
Flow rate	2.64**	-0.13	2.62**
Physical and biological attributes			
Shade (%)	0.36	-0.27	0.87
Surface rocks (%)	-0.20	0.57	-1.05
Sandbanks (%)	3.94***	3.39***	2.61*
Exposed soil (%)	-0.48	-0.24	-0.81
Native shrubs (%)	1.53	0.34	1.69
Invasive shrubs (%)	-0.81	0.50	-2.11*
Grass (%)	0.59	0.72	-0.61
Reeds (%)	-0.63	-0.44	-0.64
Aquatic macrophytes (%)	4.45***	3.62***	1.95
Water Hyacinth (%)	-0.21	-0.57	0.01

Values indicated are t-values (* significant at 0.05; ** significant at 0.01; *** significant at 0.001)

value of < 3 was used. To assess the relative importance of individual environmental variable with significant collinearity on structuring of the Odonate assemblage, variance partitioning analysis was carried out and the result of variance partitioning was expressed graphically using a Venn diagram. All the above analyses were carried out using the CANOCO5 software developed by ter Braak and Šmilauer (2012).

6.4 RESULTS

The results obtained on the influence of observed environmental variables on species richness and assemblages of overall Odonata, Anisoptera and Zygoptera are presented below.

6.4.1 Influence of environmental variables on overall Odonate species richness

The number of Odonate species observed across the study sites covering forest streams, riverine sites, tanks and paddy fields varied among the aquatic habitats. Among the five aquatic habitats, forest streams were found to be the most speciose aquatic habitat ($n=50$) followed by riverine sites ($n=46$), seasonal tanks ($n=26$), permanent tanks ($n=19$) and the least was paddy fields with 15 species. The GLMM analysis performed to assess the influence of environmental variables on the overall Odonate species richness was found to be significant ($p<0.0001$, $F=6.12$, $DF=18,171$). The influence of environmental variables separately on Anisoptera richness and Zygoptera richness were also found to be significant (Anisoptera: $p=0.00001$, $F=3.7$, $DF=18,157$; Zygoptera: $p=0.00076$, $F=2.645$, $DF=18,137$). The individual effects of physical, physicochemical and biological parameters on total species richness of Odonates are furnished in Table 6.1.

Among the 18 environmental variables subjected to the analysis, four variables *viz.*, water temperature, flow rate, percentage of sandbanks and percentage of aquatic macrophytes had a significant influence on the overall species richness of Odonates (Table 6.1). Environmental variable *viz.*, pH, conductivity, percentages of surface rocks, exposed soil, invasive shrubs, reeds and water hyacinths had a negative influence on the overall species richness. Species richness for Anisoptera was significantly influenced by percentage of sand banks ($p<0.001$) and percentage of aquatic macrophytes ($p<0.001$) followed by wind speed ($p<0.01$), water temperature ($p<0.01$) and relative humidity ($p<0.05$). Significant negative influence by

conductivity was observed on the species richness of Anisoptera (Table 6.1). The species richness of Zygoptera was significantly influenced by the variables namely, flow rate ($p < 0.01$), percentage of sand banks ($p < 0.05$) and invasive shrub cover. Invasive shrub cover showed a negative influence ($p < 0.05$) on the species richness of Zygoptera (Table 6.1).

6.4.2 Influence of environmental variables on adult Odonate assemblages

The outcomes of three CCA were analysed individually to establish the influence of environmental variables on the overall Odonate, Anisoptera and Zygoptera assemblages (Table 6.2). Of the 18 variables observed only 14 variables were included in the forward selection method to assess the influence of environmental variables on overall Odonate assemblage. A total of 8 and 15 variables were included based on the forward selection method to establish their influence on assemblages of Anisoptera and Zygoptera respectively.

The CCA carried out with 14 environmental variables to estimate their extent of influence on overall Odonate assemblage based on canonical axes indicated that all the first four canonical axes were found to be significant ($F=11.6$, $P=0.024$ and $F=2.58$, $P=0.002$). In the overall variation of Odonate assemblage, 19.2% was explained by the environmental variables, 12.2% by the first four axes of the species data and 63.0% by the species-environment relationship (Figure 6.1).

A clear-cut difference in Odonate assemblages of different aquatic bodies was revealed from the CCA performed (Figure 6.1). Odonate assemblages of lotic systems are located in the positive end of axis 1 and assemblages of lentic systems such as seasonal tanks, permanent tanks and paddy fields are located in the negative end of axis 1. Axis 2 separates the assemblages based on the permanence of water, wherein sites with permanent water are located in the negative end of axis 2 and seasonal water sites (drier gradient of water permanence) are located in the positive end of axis 2. The forest streams and riverine assemblages are predominantly located in the positive end of axis 1. However there is an overlap of forest streams and river assemblages with the negative end of axis 1 and 2.

The values of environmental variables namely, conductivity and water temperature were higher in permanent tanks, seasonal tanks and paddy fields. These

Table. 6.2. Canonical correspondence analysis results for the influence of environmental variables on Odonate assemblages. Pseudo-F-values displayed for simple effects of variables (SS) and forward selection of variables (FS).

Variables	Overall		Anisoptera		Zygoptera	
	SS	FS	SS	FS	SS	FS
Weather parameters						
Temperature (maximum)	2.4 **	-	2.4 **	-	3.3**	-
Relative humidity	4.1 **	3.0*	3.3 **	2.3*	4.5**	2.8*
Rainfall	1.7	-	1.9	-	2.7	2.9*
Water parameters						
Water temperature	3.4**	1.8*	4.6 **	2.1*	2.4*	2.3*
pH	1.3	-	1.5	-	1.4	-
Conductivity	5.0**	2.0**	3.7 **	-	10.8**	4.8**
Flow rate						
Dry	1.4	-	1.7	-	0.7	-
Still/stagnant	7.9**	7.9**	6.9 **	3.3**	15.5**	15.5**
Glide	3.7**	-	3.6 **	-	6.1 **	-
Rapid	4.1**	3.0**	2.9 *	-	6.3**	4.0**
Physical and biological attributes						
Shade %	3.8**	3.6**	4.3 **	2.8*	4.8**	2.7**
Surface rocks %	6.8**	2.5*	7.5 **	-	9.6**	5.1**
Sand banks %	6.6**	1.6*	9.0 **	9.0**	6.2**	2.2*
Exposed soil %	3.8**	2.2*	3.5 *	3.7*	2.0	-
Native shrubs %	5.9**	2.3**	5.0 **	-	10.0**	4.9**
Invasive shrubs %	3.0**	2.0*	4.1 **	2.5*	2.8**	1.9*
Grass %	2.4**	1.7*	2.1 *	-	4.8**	2.0*
Reeds %	1.3	-	1.2	-	2.7**	2.7**
Aquatic macrophytes %	2.6*	3.0*	3.4 **	3.3*	2.5*	3.1*
Water Hyacinth %	5.9**	3.4*	3.6 **	-	10.6**	5.1**

(* significant at 0.05 ** significant at 0.01, *** significant at 0.001)

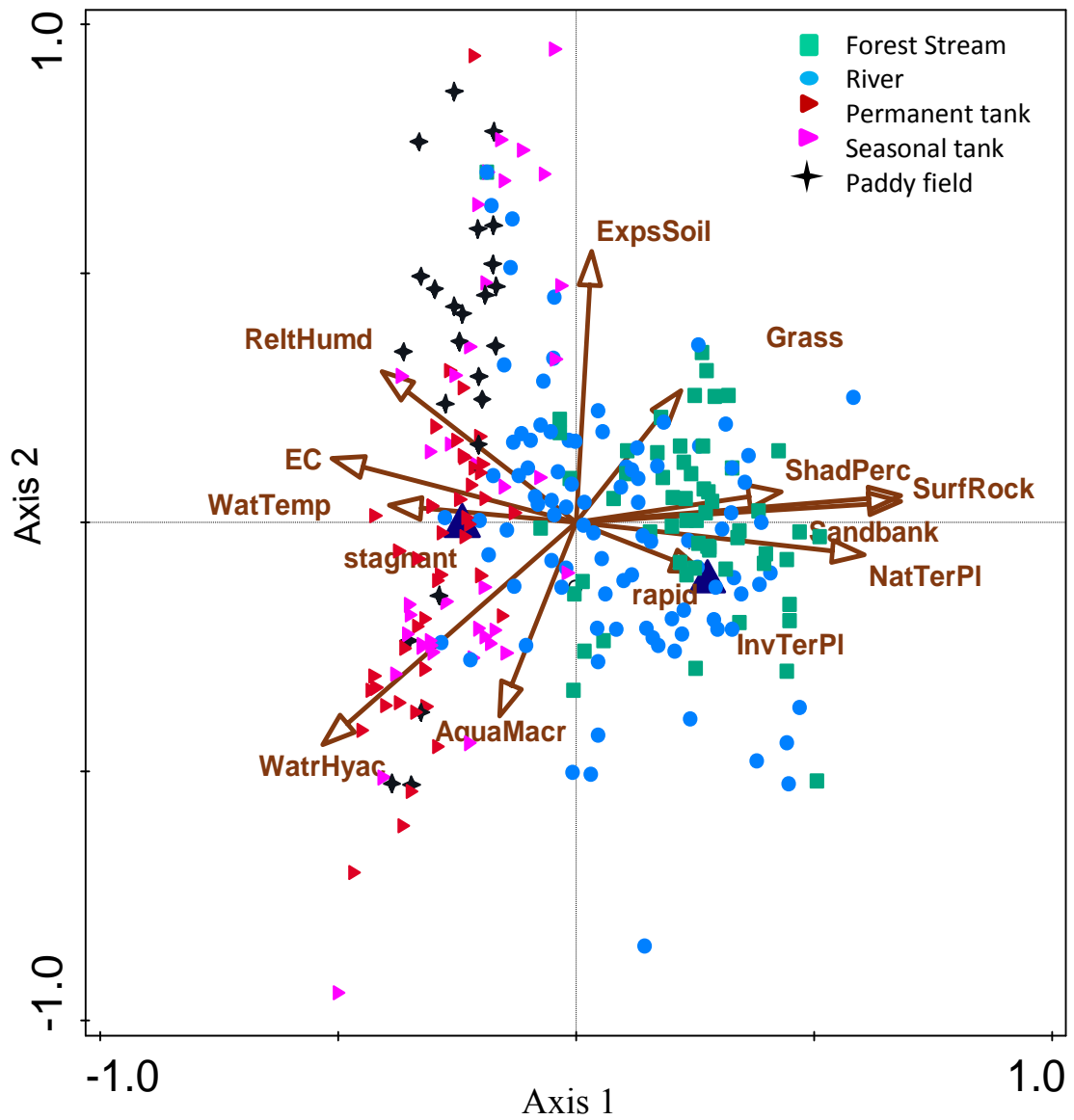


Figure 6.1. CCA ordination showing the effect of environmental variables on the overall odonate assemblage (sites-environment biplot).

aquatic bodies were also positively associated with aquatic macrophyte coverage. In forest streams and river systems were associated with greater vegetation structures such as native terrestrial shrubs, invasive terrestrial shrubs and grass cover. Here, conductivity and water temperature were found to be lower when compared to lentic systems. The environmental variables such as shade, sand banks surface rocks were also found to be associated with forest streams and riverine sites (Figure 6.2).

The CCA revealed that the species found to be associated with running water were grouped at the positive end of axis 1 and they include species viz., *Vestalis apicalis*, *V. gracilis*, *Libellago lineata*, *Prodasineura verticalis*, *Euphaea dispar*, *Onychothemis testacea*, *Agriocnemis splendidissima*, *Onychogomphus nilgiriensis* and *Burmagomphus laidlawli* (Figure 6.2). The species such as *Trithemis aurora*, *T. festiva*, *Paragomphus lineatus*, *Orthetrum glaucum* and *O. pruinosum* were also found to be positively associated with surface rock and sand bank at the positive end of axis 1. *Neurobasis chinensis*, *Pseudagrion rubricsps*, *Copera marginipes*, *Rhynocypha bisignata* were positively associated with native terrestrial shrubs.

In the negative end of axis 1 the species (*Pseudagrion decorum*, *P. microcephallum*, *Acisoma panorpoides* and *Rhodothemis rufa*) associated with non-invasive macrophytes are found. Likewise, the species (*Ischnura senegalensis*, *Ceriagrion coramandelianum*, *Brachydiplax chalybea*, *Rhyothemis variegata* and *Crocothemis servilia*) associated with the invasive aquatic macrophytes (water hyacinth) were also found.

Species such as *Pantala flavescens*, *Diplacodes trivialis*, *Ischnura aurora* and *Lestes elatus* are associated with a drier hydroperiod conditions in negative end of axis 2. Species like *Ictinogomphus rapax* and *Anax guttatus* that were associated with all aquatic bodies were clustered in the middle of the axes (Figure 6.2).

Partitioning of variance analysis indicated that a combination of factors influence Odonate assemblages. The biological factor in combination with physical and physic-chemical factors was the most significantly affecting factor accounting for 27.3% of the total variation. However, the parameters constituting the biological factor individually accounted for only 1.4% of the total variation. Physical factors and physic-chemical factors accounted for 21.1% and 17.9% of the total variation

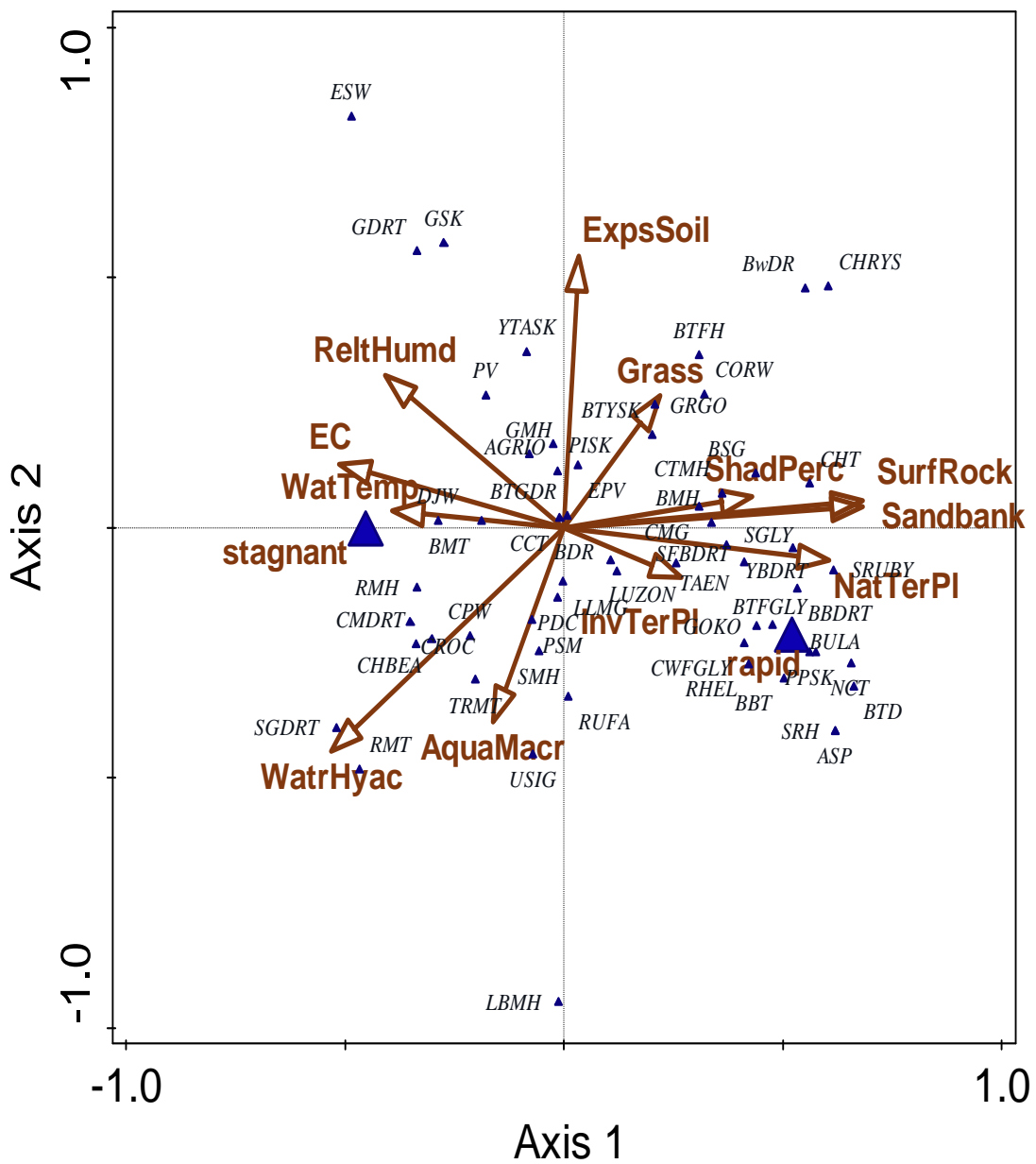


Figure 6.2. CCA ordination showing the effect of environmental variables on the overall odonate assemblage (species-environment biplot)

*Species codes provided in Appendix 5

respectively. The combined effect of all the three factors accounted for 10.1% of the total variation (Figure 6.3).

6.4.3 Influence of environmental variables on Anisoptera

The CCA for 39 species of Anisoptera was performed using 18 environmental variables, of which only eight variables were selected in the forward selection method (Table 6.2). The first canonical axis and all four canonical axes of the model were significant ($F=12.3$, $p=0.018$ and $F=2.45$, $p=0.002$). The environmental variables accounted for 14.70% of variation in Anisoptera. The first axis accounted for 6.3% variation in species data and 43.16 % variation of the species-environment relationship. Similar to the overall Odonate CCA, axis 1 separated the assemblages into lentic and lotic groups and axis 2 separated the assemblages based on permanence of water. The negative side of axis 2 comprised of species tolerant to dry period (Figure 6.4).

In the positive end of axis 1, species such as *Onychogomphus nilgiriensis*, *Orthetrum pruinosum*, *O. glaucum*, *Trithemis aurora*, *Tholymis tillarga* were positively associated with increased sandbank cover. Species such as *Onychothemis testacea* and *Orthetrum taeniolatum* were strongly associated with invasive terrestrial plants. Exposed soil remained as a significant variable which affected Anisoptera. Species like *Bradinopyga geminata* and *Orthetrum sabina*, were associated with exposed soil. Species such as *Rhyothemis variegata*, *Urothemis signata*, *Acisoma panorpoides*, *Brachydiplax sobrina*, *Tetrathemis platyptera* were strongly associated with aquatic macrophytes (other than water hyacinth). *Burmagomphus laidlawi*, *Orthetrum triangulare*, *Trithemis festiva* and *Paragomphus lineatus* were associated with increased shade.

6.4.4 Influence of Environmental variables on Zygoptera

The CCA for 19 species of Zygoptera using 15 environmental variables, selected by the forward selection method was analysed (Table 6.2). The first canonical axis and all four canonical axes of the model were significant ($F=18.762$, $p=0.002$ and $F=3.92$, $p=0.002$). The variables accounted for 32.30% of variation in damselfly assemblage. The first axis accounted for 11.63% variation in species data and 35.97 % variation of the species-environment relationship. The first four axes

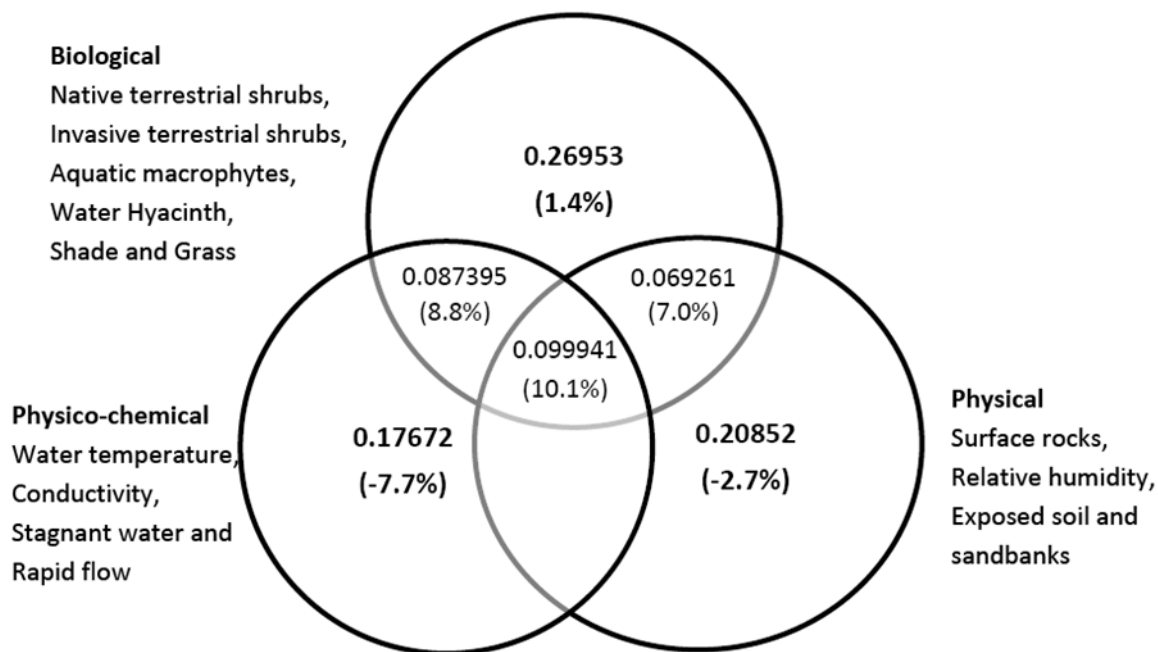


Figure. 6.3 Variance partitioning of the relative influence of biological, physical and physicochemical factors on Odonate composition of environmental variables

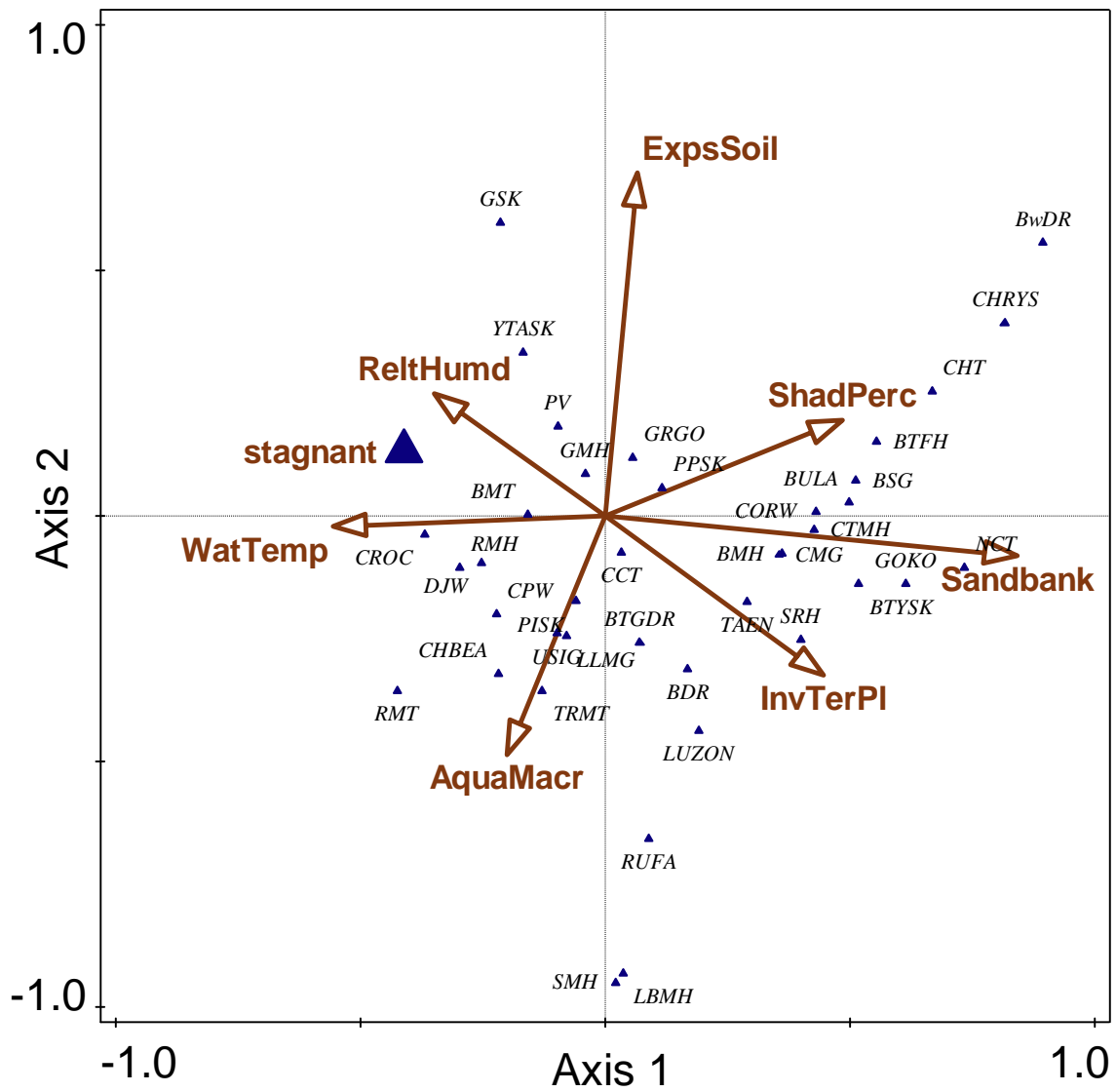


Figure 6.4. CCA ordination showing the effects of environmental variables on Anisoptera

together accounted for 23.63% variation in the species data and 73.08% of the species-environment relationship. In the CCA, axis 1 segregated the assemblage based on hydroperiod gradient. The positive end of axis 1 comprised of permanent hydroperiod regimes and the negative end of the axis 1 comprised of the drier gradient. The second axis separated Zygoptera assemblage based on their presence in lentic and lotic systems. In which the positive end of the axis 2 comprised of lentic groups and the negative end comprised of lotic groups (Figure 6.5).

Stagnant flow rate was the most significant factor affecting Zygoptera. Biological factors such as, the invasive aquatic macrophyte (water hyacinth), native terrestrial shrubs significantly affect composition. Physical parameters of the site such as surface rocks and physicochemical parameters such as conductivity affected Zygoptera (Table 6.2). Commonly observed species such as *Ceriagrion coromandelianum* and *Ischnura senegalensis* found mostly in stagnant sites were associated with the invasive macrophyte (water hyacinth). Species such as *Prodasineura verticalis*, *Pseudagrion rubriceps*, *Vestalis gracilis*, *V. apicalis*, *Neurobasis chinensis*, *Rhynocypha bisignata* and *Libellago lineata* are strongly associated with surface rocks in rapid flowing waters. Also, *Vestalis gracilis*, *Prodasineura verticalis*, *Copera vittata*, *C. marginipes* and *Pseudagrion rubriceps* were associated with native terrestrial shrubs and sand banks as well.

6.5 DISCUSSION

Variation in ecological communities is the outcome of prevailing environmental heterogeneity due to many variables. Environmental heterogeneity is an important driver of species diversity, and its influence on species richness has been analysed for numerous taxa, in diverse ecological settings, and over a large range of spatial scales (Stein *et al.* 2014). Stein and Kraft (2015) reported the existence of ambiguity in the measures of environmental variables across several studies in deciding the relationship between heterogeneity and diversity. Yang *et al.* (2015) opined that the relationship between heterogeneity and diversity is influenced by the environmental gradient and it needs further empirical studies. Several studies have been conducted to understand the relationship between species richness and environmental heterogeneity in Odonates involving different variables of environment: nature of vegetation (Painter, 1998; Stewart and Samways, 1998;

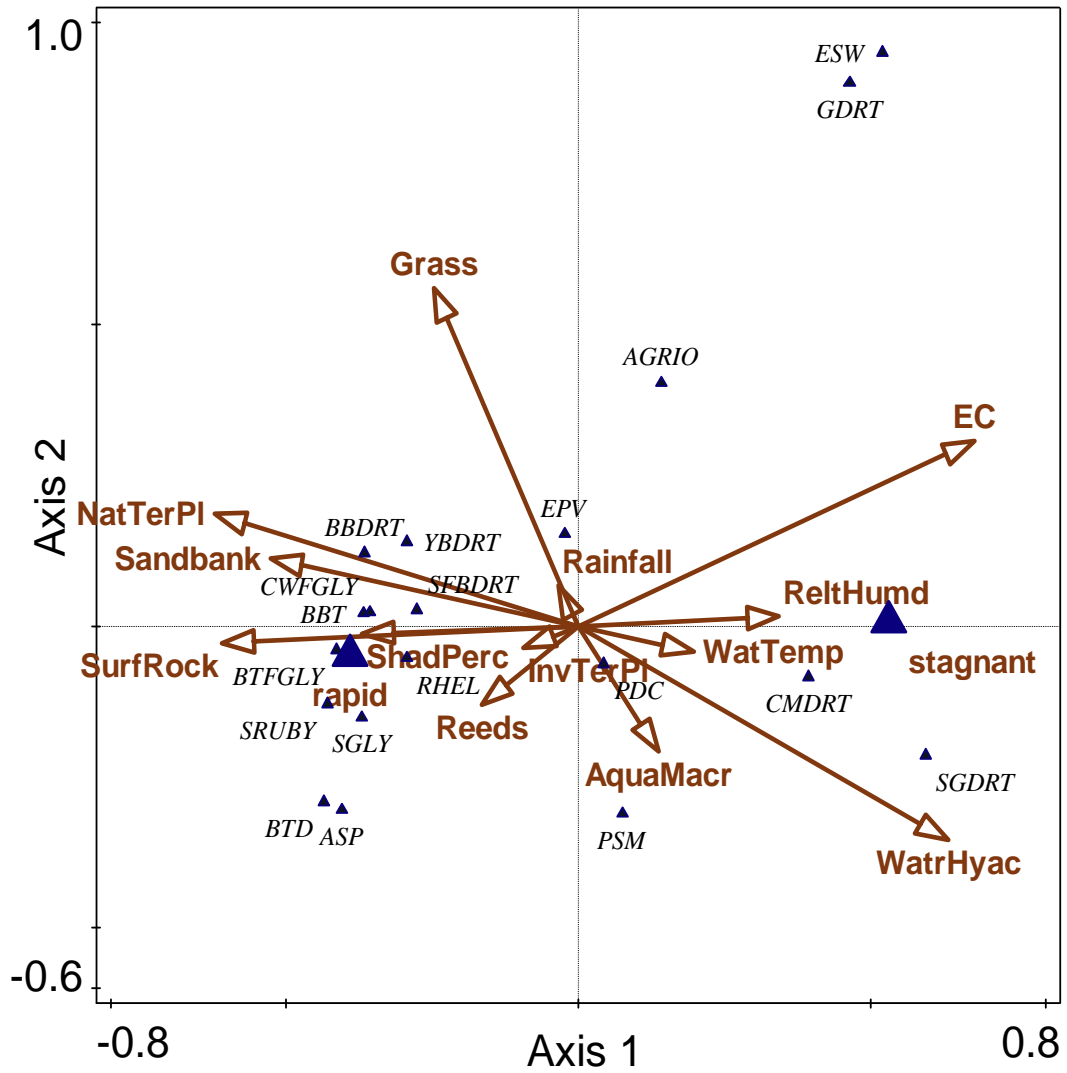


Figure 6.5. CCA ordination showing the effect of environmental variables on Zygoptera

Samways and Sharratt, 2009), vegetation and water parameters (Keil *et al.* 2008), and water parameters (Chandana *et al.* 2012; Kietzka *et al.* 2016). Climatic factors such as latitudinal and altitudinal gradients, along with vegetation structure and physicochemical factors of a location have been shown to affect Odonate richness (Heino, 2009). In the present study an attempt has been made to understand the influence of a set of biological, physical and physicochemical factors on Odonate richness and assemblages.

Out of 18 environmental variables involved in this study, four variables *viz.* water temperature, flow rate, percentage of sand cover and percentage of aquatic macrophytes showed significant positive influence on the species richness of overall Odonates and Anisoptera. The environmental variables *viz.* flow rate, percentage of sand cover was found to have positive influence on Zygoptera species richness. Invasive shrubs on the other hand were found to have a negative influence on species richness of Zygoptera. The role of water temperature on Odonate assemblage was reported by Corbet (1999), Hassall *et al.* (2007) and Hassall and Thompson (2008). Jeanmougin *et al.* (2014) reported the positive influence of water temperature on the Odonate diversity based on studies conducted in the ponds of Paris. The recent study of Kietzka *et al.* (2016) on the influence of different environmental variables on Odonate assemblages revealed that the water temperature was the most influencing environmental variable.

In this study, Odonate assemblages were largely segregated based on flow regime and hydroperiodicity, *i.e.* permanence of water. Generalist species such as *Pantala flavescens*, *Diplacodes trivialis*, *Ischnura aurora* and *Lestes elatus* are associated with a drier hydroperiod conditions. The situation is in accordance with the study of Subramanian *et al.* (2008), who observed generalist species such as *Pantala flavescens*, *Orthetrum Sabina* and *Diplacodes trivialis* in riparian sections and wetlands. The studies of Pires *et al.* (2017) on Odonate assemblages in ponds with different hydroperiod lengths indicated the restricted occurrence of some genera in long-hydroperiod ponds and reported that reduction in hydroperiod length would favour habitat-generalist taxa in lentic ecosystems. The species *viz.* *Vestalis apicalis*, *V. gracilis*, *Libellago lineata*, *Prodasineura verticalis*, *Euphaea dispar*, *Onychothemis testacea*, *Agriocnemis splendidissima*, *Onychogomphus nilgiriensis* and *Burmagomphus laidlawi* were found in the habitats of running water. McPeck (2008)

reported that species demarcation across Odonates was clear-cut between flowing and standing water habitats. This could be attributed to the well-known hypothesis where, biological communities are influenced and limited by its distribution by the changes in physical and biological properties along a river continuum (Vannote *et al.* 1980).

An overlap of Odonate communities between the forest streams and river sites with lentic species was observed in this study. This could be due to forest streams and rivers which are seasonal. These locations support a lentic habitat before they become dry, which are colonised by the generalist species. Species such as *Dysphea ethela* and *Onychothemis testacea* were associated with fast flowing river sites. It is known that lotic species are restricted to its habitat due to the availability of high dissolved oxygen in fast flowing waters; species which can tolerate lower oxygen level are found in slow flowing or lentic sites (McPeck, 2008). Other physicochemical parameters such as pH, water temperature and salinity have also known to affect Odonate distribution (Corbet, 1999; Kinvig and Samways, 2000, Kietzka *et al.* 2016). In the present study, species richness was highest in forest streams and river sites than the lentic site which is consistent with the study by Opper (2005). Forest and river communities were largely influenced by the vegetation structure, shoreline conditions and flow rate in the present study. Forest and river communities were negatively influenced by high salinity and water temperature.

Invasive plants have shown to positively influence Odonate assemblages. In the study area invasive plant species such as *Lantana camara*, *Chromolaena odorata*, *Ageratina adenophora* and *Parthenium hysterophorus* are widely prevalent even in the fringes of forest area. This does not comply with studies from the Maltese islands where invasive reeds have reduced the growth of submerged macrophytes, which threatens the Odonate population (Balzan, 2012). Similarly, invasive plants are known to alter water conditions (Joubert, 1986) and reduce the richness of Odonates (Samways and Sharratt, 2009). Many generalist Odonates were associated with the invasive aquatic macrophyte namely., *Eichhornia crassipes*.

Odonate communities found in lentic waters were associated with aquatic macrophytes. Aquatic macrophyte support Odonate communities in egg laying, shelter and protection from fish. Species such as *Coeragrion coromandelianum*, *Ishnura senegalensis* are able to tolerate wide range of environmental conditions

unlike many Zygopterans which are highly sensitive to environmental conditions and are restricted to riverine and forested areas. Oppel (2005) shows that closed forest canopy supports many Zygopterans and they are good indicators for landscapes with little human interference.

Water persistence and the existence of floating macrophytes were the factors most likely to trigger the formation of species assemblage (Schindler *et al.* 2003). Studies have shown that presence of dragonflies determine the quantity and quality of shoreline structures such as sand banks, rocks and shade (Oppel, 2005). In this study, sand banks positively influenced overall Odonate assemblages. Although sand banks are considered poor habitats for aquatic insects (Anderson and Wallace, 1978) they are known to be preferred habitats for the family Gomphidae (Fraser, 1931, 1934; Abbott 2001). In the present study, Gomphids like *Paragomphus lineatus*, *Onychogomphus nilgiriensis* were found to be highly associated with sandy riparian sections.

The present study covers a wide range of aquatic habitats with moderate to heavily disturbed sites, where a combination of environmental variables influences the Odonate assemblage. The present study did not cover core forest areas but sampling covered forest streams in the fringes of the forest. This could be the reason for the absence of many of rare Odonates which have been recorded in the region earlier (Fraser, 1931). Studies on Odonates (Kietzka *et al.* 2016) and aquatic macroinvertebrates (Hill, 2015) suggests that, in pristine undisturbed sites, physiocochemical factors play the important role in Odonate assemblages and in disturbed sites vegetation structure and other factors play a role in assemblages. The intermediate disturbance hypothesis suggests that diversity, will be greatest in regions where there is moderate disturbance (Connell, 1978). At moderate disturbance, the equilibrium requirement of competitive exclusion is not realised and species packing is maximised (Ward, 2008). It is crucial to understand habitat association of Odonates in assessing aquatic habitats and its conservation. Thus, the present result suggests that waterbodies and its associated terrestrial habitats in the region influence the Odonate composition.

Based on the present study it is now clear that the biotic and abiotic factors in the habitat influence the overall and individual (Anisoptera and Zygoptera)

assemblages. However, the exploitation of species richness as an indicator of habitat quality cannot be made and it would be misleading as indicated by Dolný *et al* (2012) and Monteiro-Júnior *et al* (2014) since degraded habitats could be occupied by generalist species. Moreover, the influence of specific environmental variables on Odonate assemblages is inconclusive since most of the studies conducted are done in isolation and are data deficient as indicated by Orr (2004) for making clear-cut conclusions on the role of environmental variables on Odonate assemblages. However, the present investigation throws some light on the influence of environmental variables on the Odonate assemblages across the study area in Coimbatore district.

6.6. CONCLUSION

Species richness of Odonates was largely influenced by water temperature, flow rate, vegetation and habitat structure. Odonate compositions were largely segregated based on the flow conditions of aquatic systems. Composition in lentic and lotic systems differed largely due to vegetation structure, water quality and physical structures of the habitat. Both aquatic macrophytes and terrestrial shrubs influenced Odonate structure in various aquatic habitats. Habitat structures such as sand banks, surface rocks were found to influence Odonate assemblages. The relationship of environmental factors on Odonate assemblages is complex and a combination of biological, physical and physicochemical parameters influenced Odonate assemblage in the study area.

CHAPTER 7

SUMMARY AND CONCLUSION

Freshwater resources world over are under tremendous pressure due to landscape modification and pollution caused by various anthropogenic activities. It is highly critical to document and assess global biodiversity in the present scenario. Since Odonates are increasingly being used in the assessment of freshwater habitats due to their species specific sensitivity to habitat modifications. Also the feasibility and easy access in monitoring Odonates have made them important model organisms in ecological and evolutionary studies. In India systematic studies on population assessment of Odonates are scarce, where most of the studies are on check-listing of regional Odonates. With this background, the present study throws light on the diversity, distribution and composition of Odonates in Coimbatore district. Additionally, the environmental variables which influence the distribution of Odonates in various aquatic bodies has also been presented

7.1. Odonate community profile and species composition

Coimbatore district which lies close to the Western Ghats, were found to have a rich Odonate diversity. Cataloguing of Odonates in Coimbatore has been attempted since the early 1930's when Fraser documented 48 species in certain forest reserves of Coimbatore district. Later many studies have made small scale check-listing in tanks and rice fields of the district enlisting a total of 23 and 22 species respectively. In the present study reconnaissance survey in various aquatic habitats in Coimbatore district was conducted over a year. Followed by, systematic sampling in aquatic habitats such as forest streams, river, seasonal tanks, permanent tanks and paddy fields over two years in 24 intensive study locations, have enlisted 70 species of Odonates to the district. Eighteen species recorded in the present study are first time records to the district. This brings the total Odonate in the region to 87 species. Of the families Libellulidae (36) and Coernagrionidae (11) were the most speciose family. Forest streams had the highest number of species (51) followed by rivers (49). The aquatic habitat with least number of recorded species was from paddy fields (15). A total of 22 endemic species has been recorded in the district. Despite the intensive sampling in the region for over two years, nearly 16 species from earlier records were not

observed in the present study, which could probably indicate large level change in the terrestrial and aquatic habitats in the district.

7.2. Diversity and distribution of Odonates in space and time

Both spatial and temporal variability in Odonate diversity, distribution and composition were recorded in various aquatic habitats of Coimbatore. Forest streams and rivers were the most diverse aquatic systems. They had low evenness and high richness, whereas lentic systems such as seasonal tanks, permanent tanks and paddy fields were highly even and low in richness. Similarly, community composition was similar between lentic systems and varied with lotic systems such as forest streams and river. Odonate composition between forest streams and rivers were also varied, which indicates the habitat specificity of many forest species. Similarity of the study locations that were analysed through distance matrix indicated that, habitat structures had more influence on the community similarity of locations than regional landscapes as such. were less similar with lentic locations. There was variation in community composition seasonally, which is primarily due to increase seasonal abundance of certain species and also due to variation in availability of water in aquatic bodies seasonally. There was a constant change in composition over the dry months of December-January and February-March with the monsoonal months of June-July and August-September.

7.3 Factors influencing Odonate community composition

Odonates assemblages are driven by various environmental factors in their distribution. Assemblages were primarily segregated based on the flow conditions of water and also on the availability of water in the aquatic system. Species which were associated with lotic water systems were strongly associated with vegetation structure such as terrestrial shrubs and shade. They were also positively associated with shoreline conditions such as sandbanks and surface rocks. Species which were associated with lentic water sites were more associated with aquatic macrophytes, certain species showed positive association even with the invasive aquatic macrophyte *Eichornia crassipes*. Species present in lentic water systems were positively associated with high values of water temperature and conductivity, unlike species present in lotic systems which were negatively influenced by the above mentioned water parameters. Odonates in

Coimbatore district were influenced by a combination of biological, physical and physicochemical factors. Ultimately, this study provides information on the diversity and distributional pattern of Odonates in the region along with their habitat preferences.

7.4 Future directions

The present study is limited to the water bodies in human influenced areas, including fringe areas of forest. It has been inferred that forest areas have high diversity and endemism of Odonates, hence more intensive studies in core areas of forest along with larval studies will bring out the complete picture of the Odonate community in the region.

Biotic index based on Odonates are suggested as a good biomonitoring tool for the assessment of the health of aquatic systems. However, index values for each species has to be calculated, for this purpose more elaborate and focused study on all the species are required. The role of Odonates as biocontrol agents of insects in agricultural landscapes needs to be assessed.

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Appendix 1. List of locations surveyed in the study

Locations	Habitat	Altitude (m)	Co-ordinates
Bhavani river basin			
Kallar	FS	379	N 11° 20' 15.0" E 76° 52' 54.1"
Batrakaliamankovil	R	315	N 11° 17' 37.6" E 76° 53' 30.4"
Vilamarathur	R	327	N 11° 16' 55.4" E 76° 51' 54.9"
Athikadavu	R	449	N 11° 12' 50.82" E 76° 45' 16.64"
Chavadiyur	R	486	N 11° 09' 23.2" E 76° 55' 38.9"
Chavadiyur- Mulli	R	481	N 11° 09' 52.27" E 76° 41' 01.53"
SACON, Anaikatty	FS	626	N 11° 05' 45.48" E 76° 46' 46.32"
Kondanur	FS	629	N 11° 06' 27.41" E 76° 47' 37.27"
Noyyal river basin			
Kovai Kutralam waterfall	FS	550	N 10° 56' 19.79" E 76° 43' 13.9"
Nandankarai checkdam	FS	496	N 10° 56' 00.32" E 76° 43' 22.26"
Siruvani checkpost	FS	469	N 10° 56' 36.0" E 76° 43' 13.9"
Madhampatty	R	429	N 10° 58' 38.0" E 076° 51' 29.0"
Perur	R	416	N 10° 58' 45.1" E 076° 54' 52.0"
Somayampalayam tank	W	463	N 11° 02' 43.71" E 076° 53' 43.61"
Perur big tank	W	411	N 10° 58' 08.15" E 076° 55' 51.35"
Nagarajapuram tank 1	W	425	N 10° 59' 58.73" E 076° 54' 31.26"
Nagarajapuram tank 2	W	426	N 11° 00' 05.62" E 076° 55' 13.38"
Paddy Breeding station	W	421	N 10° 59' 42.3" E 076° 55' 02.2"
TNAU- Wetlands	W	421	N 11° 00' 10.8" E 076° 55' 19.3"
Vedapatty lake 1	W	420	N 10° 59' 03.08" E 076° 54' 18.60"
Vedapatty lake 2	W	417	N 10° 59' 06.1" E 076° 54' 23.0"
Muthanankulam 1	W	426	N 11° 00' 12.8" E 076° 55' 55.8"
Muthanankulam 2	W	422	N 11° 00' 11.4" E 076° 55' 38.9"
Kuruchi lake 1	W	405	N 10° 58' 11.4" E 076° 57' 27.7"
Kuruchi lake 2	W	402	N 10° 57' 56.06" E 076° 58' 09.29"
Ukkadam tank	W	409	N 10° 57' 56.06" E 076° 58' 09.29"
Valankulam tank	W	407	N 10° 59' 28.87" E 077° 57' 04.01"
Singanallur lake 1	W	390	N 10° 59' 50.49" E 077° 01' 15.59"
Singanallur lake 2	W	391	N 10° 59' 08.20" E 077° 01' 30.72"
Sulur lake	W	364	N 11° 01' 38.91" E 077° 06' 34.36"
Pallapalayam lake	W	384	N 10° 59' 23.77" E 077° 04' 25.42"
Aliyar river basin			
Aanamalai town	R	251	N 10° 34' 48.92" E 076° 56' 19.69"
Ambarampalayam	R	226	N 10° 38' 15.22" E 076° 56' 47.97"
Athupollachi	R	221	N 10° 39' 28.75" E 076° 55' 44.41"
Kaliapakoundenpudur	R	204	N 10° 38' 15.22" E 076° 56' 47.97"
Uthukuli pond	W	258	N 10° 39' 24.55" E 076° 58' 37.82"
Palayur pond	W	306	N 10° 35' 53.66" E 077° 03' 18.16"
D. Kalipalayam Wells	W	231	N 10° 41' 36.99" E 076° 57' 04.01"

Appendix 2. Checklist of Odonates recorded in Coimbatore.

Record references: **F¹**- Fraser 1924; **F²**- Fraser 1931; **TK**- Ramakrishna Ayyar & Krishna Ayyar 1933; **F³**- Fraser- (1933-36); **AB**- (Abraham 1959); **G**- Gunathilagaraj et al 1999; **AG¹**- Arulprakash & Gunathilagaraj 2009; **AG²**- Arulprakash & Gunathilagaraj 2010a; **AG³**- Arulprakash & Gunathilagaraj 2010b; **KK**- Karthika & Krishnaveni 2014; **MP**- Muhil & Pramod (Present study).

* Endemic to India; ** Endemic to Western Ghats; **F**-Forest Streams; **R**-Rivers; **T**- Tanks and Ponds; **P**- Paddy fields.

Species	Habitat	Records of distribution	Recorded by
Aeshnidae			
<i>Anaciaeschna jaspidea</i> Burmeister, 1839	T	Crepuscular species also recorded in the urban areas to light source	KK, MP
<i>Anax guttatus</i> Burmeister, 1839	F,R,T	Throughout Coimbatore	AG ³ , MP
<i>Anax immaculifrons</i> Rambur, 1842	F,T	Throughout Coimbatore	TK, AB, MP
<i>Anax parthenope</i> Selys, 1839	T	Crepuscular species recorded in tanks	F ³
<i>Gynacantha dravida</i> Leiftnick, 1960	F	Crepuscular species also recorded in the urban areas to light source	F ^{2,3} , AG ³ , MP
<i>Hemianax ephippiger</i> Burmeister, 1839	P	Paddy field	TK, AB, AG ³
Gomphidae			
<i>Asiagomphus nilgiricus</i> Laidlaw, 1922**	R	Bhavani River	F ³
<i>Burmagomphus laidlawi</i> Fraser, 1924**	R	Bhavani River	F ³ , MP
<i>Gomphidia kodaguensis</i> Fraser, 1923**	F	Boluvampatti Forest	F ² , MP
<i>Gomphidia</i> sp (cf)	R	Bhavani River	MP
<i>Heliogomphus promelas</i> Selys, 1873**	F	Boluvampatti Forest	F ³
<i>Ictinogomphus rapax</i> Rambur, 1842	F,R,T	Throughout Coimbatore	F ² , TK, AB, AG ² , MP
<i>Megalogomphus superbus</i> Fraser, 1931**	F	Boluvampatti Forest	F ²
<i>Microgomphus souteri</i> Fraser, 1924**	F	Boluvampatti Forest	F ²
<i>Onychogomphus nilgiriensis</i> Fraser 1922**	F,R	Boluvampatti Forest, Bhavani River	F ³ , MP
<i>Paragomphus lineatus</i> Selys, 1850	F	Anaikatty Forest, Kallar, Boluvampatti Forest	F ³ , MP
Libellulidae			
<i>Acisoma panorpoides</i> Rambur, 1842	F,R,T,P	Forest streams, rivers, rural tanks and paddy fields	AG ³ , MP
<i>Aethriamanta brevipennis</i> Rambur, 1842	F	Boluvampatti Forest	MP
<i>Brachydiplax chalybea</i> Brauer, 1868	R,T	River rural and urban tanks	MP

Species	Habitat	Records of distribution	Recorded by
<i>Brachydiplax sobrina</i> Rambur, 1842	R, T	River and tanks	MP
<i>Brachythemis contaminata</i> Fabricius, 1793	F, R, T, P	Throughout Coimbatore	AB, G, AG ^{2,3} , KK, MP
<i>Bradinopyga geminata</i> Rambur, 1842	F, R, T	Throughout Coimbatore	F ¹ , K, AG ³ , MP
<i>Crocothemis servilia</i> Durry, 1770	F, R, T	Throughout Coimbatore	TK, AB, G, AG ^{1,2,3} , KK, MP
<i>Diplacodes nebulosa</i> Fabricius, 1793	F	Boluvampatti Forest	MP
<i>Diplacodes trivialis</i> Rambur, 1842	F, R, T, P	Throughout Coimbatore	F ² , TK, AB, G, AG ^{1,2,3} , KK, MP
<i>Hydrobasileus croceus</i> Brauer, 1867	F, T	Boluvampatti Forest and rural wetlands	F ³ , MP
<i>Indothemis carnatica</i> Fabricius, 1798	F	Boluvampatti Forest, Anaikatty Forest	MP
<i>Lathrecista asiatica</i> Fabricius, 1798	F, T	Forest stream and rural ponds	MP
<i>Macrodiplax cora</i> , Brauer, 1867	F, R, T	Throughout Coimbatore	F ³
<i>Neurothemis fulvia</i> Drury, 1773		Exact location of record unknown	TK, AB
<i>Neurothemis tullia</i> Drury, 1723	R, T	Aliyar River	F ¹ , TK, AB, G, AG ² , MP
<i>Onychothemis testacea</i> Ris, 1912	R	Aliyar and Bhavani River	F ² , MP
<i>Orthetrum chrysis</i> Selys, 1891	F, R, P	All river and forested streams; also noted in rice fields	G, AG ³ , MP
<i>Orthetrum glaucum</i> Brauer, 1865	F, R, T	Forest streams, rivers and rural tanks	MP
<i>Orthetrum luzonicum</i> Brauer, 1868	F, R	All river and forested streams	F ³ , MP
<i>Orthetrum pruinosum</i> Rambur, 1842	F, R	All river and forested streams	F ² , MP
<i>Orthetrum sabina</i> Drury, 1770	F, R, T, P	All aquatic bodies	F ² , TK, AB, G, AG ^{1,2,3} , KK, MP
<i>Orthetrum taeniolum</i> Schneider, 1845	F, R	All river and forested streams	F ² , MP
<i>Orthetrum triangulare</i> Selys, 1878	F	Anaikatty and Boluvampatti Forest	MP
<i>Palpoleura sexmaculata</i> Fabricius, 1787	F	Boluvampatti forest	MP
<i>Panatala flavescens</i> Fabricius, 1798	F, R, T, P	Throughout Coimbatore	F ² , TK, AB, G, AG ^{2,3} , KK, MP
<i>Potamarcha congener</i> Rambur, 1842	F, R, T, P	Throughout Coimbatore	AG ^{2,3} , MP
<i>Rhodothemis rufa</i> Rambur, 1842	F, R, T	Forest streams, rivers and rural tanks	AG ² , MP
<i>Rhyothemis variegata</i> Linnaeus, 1763	F, R, T	Throughout Coimbatore	AB, KK, MP
<i>Tetrathemis platyptera</i> Selys, 1878	F	Anaikatty Forest	F ² , MP

Species	Habitat	Records of distribution	Recorded by
<i>Tholymis tillarga</i> Fabricius, 1798	F,T,P	Throughout Coimbatore	F ² , TK, AB, AG ^{2,3} , MP
<i>Tramea basilaris</i> Kirby, 1889	F,T	Throughout Coimbatore	F ² , TK, AB, G, AG ^{2,3} , KK, MP
<i>Tramea limbata</i> Rambur, 1842	F,R,T,P	All aquatic bodies	F ² , TK, AB, AG ^{2,3} , KK, MP
<i>Trithemis aurora</i> Burmeister, 1839	F,R,P	All river and forested streams; also recorded in rice fields	F ² , TK, AB, G, AG ^{2,3} , MP
<i>Trithemis festiva</i> Rambur, 1842	F,R	All river and forested streams	F ² , MP
<i>Trithemis kirbyi</i> Selys, 1891	F	Anaikatty Forest	F ³ , MP
<i>Trithemis pallidinervis</i> Kirby, 1889	F,R,T,P	Throughout Coimbatore	F ² , AG ² , KK, MP
<i>Urothemis signata</i> Rambur, 1842	F,R,T,P	All aquatic bodies	AG ³ , MP
<i>Zygonyx iris malabarica</i> Selys 1869**	F	Kovai Kuttralam falls in Boluvampatti Forest	AG ³ , MP
<i>Zyomma petiolatum</i> Rambur, 1842	F,R,T	Crepuscular species recorded to light source	MP
Macromiidae			
<i>Epophthalmia vittata</i> Burmeister, 1839*	F	Walayar Forest, Coimbatore	F ³
<i>Epophthalmia frontalis</i> Selys, 1871**	F	Walayar Forest ; Light Source	F ³ , AG ³
<i>Macromia cingulata</i> Rambur, 1842		Coimbatore district	F ³
Calopterygidae			
<i>Neurobasis chinensis</i> Linnaeus, 1758	F,R	All river and forested streams	F ² , MP
<i>Vestalis apicalis</i> Rambur, 1873**	F,R	All river and forested streams	F ² , TK, AG ³ , MP
<i>Vestalis gracilis</i> Rambur, 1842*	F,R	Boluvampatti Forest, Aliyar and Bhavani River	F ² , TK, AG ³ , MP
Chlorocyphidae			
<i>Libellago lineata</i> Burmeister, 1839	F,R	All river and forested streams	F ² , AG ¹ , MP
<i>Rhinocypha bisignata</i> Selys, 1853*	F,R	All river and forested streams	F ² , AB, AG ¹ , MP
Coenagrionidae			
<i>Aciagrion occidentale</i> Laidlaw, 1919	F	Boluvampatti forest	F ²
<i>Agriocnemis femina</i> Brauer, 1868	F,R,T	All aquatic bodies	MP
<i>Agriocnemis pygmaea</i> Rambur, 1842	F,R,T,P	All aquatic bodies	F ² , G, AG ^{2,3} , MP
<i>Agriocnemis splendidissima</i> Laidlaw 1919*	F,R	Boluvampatti forest and Bhavani River	MP
<i>Argiocnemis rubescens</i> Selys, 1877	P	Paddy fields	G
<i>Ceriagrion cerinorubellum</i> Brauer, 1865	P	Paddy fields	G

Species	Habitat	Records of distribution	Recorded by
<i>Ceriagrion coromandelianum</i> Fabricius, 1798	F,R,T,P	All aquatic bodies	F ² , G, AG ^{2,3} , MP
<i>Enallagma parvum</i> Selys, 1876	F	Boluvampatti Forest	MP
<i>Ischnura aurora</i> Brauer, 1865	F,R,T,P	All aquatic bodies	F ² , AB, G, AG ^{2,3} , MP
<i>Ischnura senegalensis</i> Rambur, 1842	F,R,T,P	Tanks and ponds	G, AG ^{2,3} , MP
<i>Pseudagrion decorum</i> Rambur, 1842	F,R,T,P	All aquatic bodies	TK, AG ² , MP
<i>Pseudagrion indicum</i> Fraser, 1924**	F	Boluvampatti forest	MP
<i>Pseudagrion microcephalum</i> Rambur, 1842	F,R,T,P	All aquatic bodies	AG ² , MP
<i>Pseudagrion rubriceps</i> Selys, 1876	F,R,T	Forest streams, rivers and rural tanks	F ² , MP
Platystictidae			
<i>Protosticta graveleyi</i> Laidlaw, 1915*	R	Bhavani River	F ² , MP
<i>Protosticta sanguinostigma</i> Fraser, 1922*	F	Mettupalayam Ghat	F ³
Euphaeidae			
<i>Dysphaea ethela</i> Fraser, 1924*	R	Bhavani River	MP
<i>Euphaea dispar</i> Rambur, 1842**	F	Kovai Kuttralam falls in Boluvampatti Forest	MP
Lestidae			
<i>Lestes elatus</i> Hagen in Selys, 1862	F,T,P	Tanks, Paddy fields and Forested areas	AG ^{2,3} , MP
<i>Lestes viridulus</i> Rambur, 1842	P	Paddy fields of Coimbatore	TK, G
Platynemididae			
<i>Copera marginipes</i> Rambur, 1842	F,R	All river and forested streams	F ² , MP
<i>Copera vittata deccanensis</i> Laidlaw 1917*	F,R	All river and forested streams	AG ¹ , MP
Protoneuridae			
<i>Caconeura t-coerulea</i> Fraser, 1931**	F	Boluvampatti Forest	F ³
<i>Prodasineura verticalis</i> Selys, 1860**	F,R	Bhavani, Noyyal and Aliyar river	F ² , AG ¹ , MP

Appendix 3. Physicochemical parameters in all study locations

Sites	pH			Electrical conductivity (μS)			Total dissolved salts (ppm)			Salinity (ppm)			Water temperature $^{\circ}\text{C}$		
	Mean(SD)	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
N_PBS	8.49 (0.72)	9.90	7.68	1147.88 (348.85)	1687	626	716.14 (176.83)	936	445	506.42 (121.65)	658	307	29.0 (1.6)	31.2	26.0
N_VED1	8.37 (0.21)	8.77	8.02	173.23 (100.58)	352	85	122.73 (72.25)	253	57	89.58 (51.96)	196	42	27.5 (2.3)	31.2	24.0
N_VED2	8.44 (0.69)	10.00	7.93	238.75 (138.70)	480	114.7	177.41 (89.66)	330	82.3	119.91 (66.67)	226	59.8	28.8 (2.3)	31.2	25.0
N_SC	8.49 (0.53)	9.95	8.07	57.96 (10.62)	81	47	41.11 (7.26)	56	33.6	34.18 (4.64)	44	28.4	25.7 (2.6)	31.6	22.0
N_NCD	8.63 (0.45)	9.75	8.01	99.37 (121.84)	463	45	70.93 (87.13)	331	32.8	53.84 (57.89)	227	27.6	26.6 (3.1)	32.1	23.3
N_MUTH1	7.95 (0.31)	8.50	7.54	1291.14 (422.48)	1886	632	523.78 (406.40)	960	1.15	639.14 (219.54)	897	292	26.8 (2.8)	30.8	23.3
N_MUTH2	8.11 (0.47)	8.50	6.80	1361.66 (227.49)	1700	1061	851.60 (100.51)	979	755	624.33 (229.38)	823	59	27.3 (1.9)	30.3	24.8
B_CP	8.63 (0.34)	9.15	8.06	178.75 (182.99)	679	30	126.95 (130.27)	484	21.9	80.36 (81.90)	316	21	25.8 (3.2)	30.6	22.0
N_MPTI	8.37 (0.33)	9.03	7.97	395.06 (170.67)	638	72	280.40 (120.89)	452	50.6	198.40 (86.07)	310	38	27.2 (3.6)	24.0	37.3
N_PER	8.67 (0.27)	9.13	8.36	339.92 (159.58)	607	64	240.81 (113.21)	431	45.7	169.17 (78.49)	289	36	26.8 (2.0)	28.8	23.6
N_SING1	8.77 (0.68)	9.60	8.15	1261.52 (855.03)	1854	23	477.31 (672.72)	953	1.63	658.28 (439.40)	1122	913	28.5 (4.2)	35.9	25.0
N_SING2	8.72 (0.45)	9.49	7.96	1444.75 (261.42)	1830	1250	933.00 (36.86)	960	891	551.03 (369.58)	769	1.15	27.3 (1.2)	28.8	25.0
A_ATP	8.55 (0.27)	9.13	8.10	305.6 (151.53)	683	134	218.30 (107.13)	486	95.6	158.01 (79.60)	333	66.5	28.8 (2.6)	33.6	24.7
A_KKP	8.66 (0.39)	9.30	7.84	292.8 (115.66)	525	111	213.41 (86.14)	374	79	152.33 (67.36)	255	54.5	29.2 (2.2)	32.3	24.1
A_ANM	8.53 (0.42)	9.60	8.08	280.51(138.22)	566	104.5	197.88 (97.42)	400	74.7	138.55 (66.68)	275	54.4	27.8 (2.2)	31.5	24.4
A_AMB	8.45 (0.36)	8.84	7.60	302.35 (147.41)	630	101	207.34 (95.15)	387	71.4	146.91 (66.07)	240	50.3	28.1 (2.3)	32.8	25.1
N_WTL	8.50 (0.66)	9.50	7.66	1516.20 (473.50)	1820	682	258.09 (363.31)	515	1.19	606.82 (374.35)	917	80.1	29.2 (4.3)	34.9	27.0
N_KUR1	8.34 (0.34)	8.99	7.70	822.25 (625.83)	1587	204	260.00 (76.73)	333	139	406.22 (293.00)	785	99.8	28.2 (2.4)	32.1	25.5
N_KUR2	8.05 (0.44)	8.74	7.31	370.80 (85.09)	476	270	214.76 (114.07)	308	1.56	158.51 (87.81)	237	1.07	27.0 (2.8)	31.1	24.4
B_KALR	8.47 (0.27)	8.81	7.95	113.35 (17.00)	136	85	80.58 (12.16)	96	60.9	58.83 (5.99)	66	49	25.3 (2.9)	28.0	23.0
B_BKL	8.35 (0.37)	8.83	7.63	394.23 (417.29)	1338	28	285.72 (289.04)	948	19.7	202.00 (193.79)	630	20	25.6 (2.6)	30.2	21.0
B_VIL	8.75 (0.26)	9.27	8.32	63.03 (20.58)	95	34	44.49 (14.72)	67	23.2	36.09 (9.18)	48.7	22	24.4 (1.9)	27.7	23.0
B_SAC	8.05 (0.40)	8.52	7.23	1494.36 (389.80)	1878	612	274.80 (329.80)	664	1.11	744.00 (183.06)	901	336	25.8 (1.8)	28.7	24.1
B_KOND	8.67 (0.43)	9.28	8.09	467.81 (205.67)	638	75	331.16 (146.60)	456	52	249.60 (121.86)	401	39	25.4 (0.6)	26.5	24.5

Appendix 4. Mean percentages of environmental variables observed in all 24 study locations

Sites	Shade	Surface rocks	Sandbanks	Exposed soil	Aquatic macrophytes	Reeds	Grass	Other plants	Invasive terrestrial plants	Invasive water plants
N_PBS	0	0	0	35	6	0	61.50	17.08	1.25	0
N_VED1	20.00	0	0	42.08	30.83	0	27.50	27.91	12.5	0
N_VED2	70	0.91	0.42	40.66	30.00	0	22.08	31.5	22.08	0
N_SC	58.33	4.16	25.83	13.33	12.08	0	30.41	57.91	18.33	0
N_NCD	5.00	20.00	30.00	15.83	41.66	4.58	53.33	48.33	25.00	0
N_MUTH1	5.00	0	0	7.91	65.33	4.33	14.83	23.33	19.16	60.33
N_MUTH2	0	0	0	2.91	33.25	0	4.58	14.16	7.75	30.16
B_CP	10	24.58	37.92	10.41	14.58	6.66	38.75	27.08	10.00	0
N_MPTI	0.83	11.66	12.92	30.41	8.33	42.91	32.08	28.33	10.41	0
N_PER	9.58	5.00	13.75	24.75	10.00	42.91	30.83	37.08	17.08	0
N_SING1	0	3.41	0	8.41	61.25	17.08	17.08	20.83	14.16	54.08
N_SING2	0	1.58	0	5.41	36.66	17.08	26.66	20.83	7.91	29.16
A_ATP	0	22.5	0	5.41	39.16	25.83	34.58	41.66	13.33	13.33
A_KKP	0	15.91	0	14.58	34.16	22.91	40.41	41.25	12.08	5.33
A_ANM	0	0.41	0	9.5	44.58	9.58	59.58	32.50	5.41	15.16
A_AMB	25.00	12.08	0.83	5	25.83	17.50	45.41	54.16	9.16	4
N_WTL	28.33	0	0	26.25	3.33	0	37.50	30.83	13.33	0
N_KUR1	0	0.16	0	11.25	63.75	0	15.00	16.66	8.75	25.25
N_KUR2	0	0	0	16.75	38.33	0	11.75	17.08	7.66	22.00
B_KALR	31.25	39.58	15.42	15.83	7.66	0	38.75	30.83	15.41	0
B_BKL	9.16	20.16	13.75	17.91	12.25	34.16	24.58	34.16	14.58	0
B_VIL	24.58	50.83	12.08	20	4.75	0	14.58	32.08	15.83	0
B_SAC	70.41	38.33	25.50	18.66	26.66	0	41.25	55.00	31.66	0
B_KOND	60.00	22.72	32.27	18.63	5.90	0	26.36	52.72	21.36	0

Appendix 5: Species codes and common names

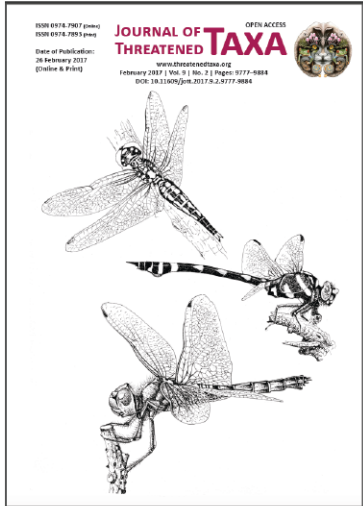
Species Codes	Scientific Name	Common name
ABT	<i>Lathrecista asiatica</i>	Asiatic bloodtail
AFEM (AGRIO)	<i>Agriocnemis femina</i>	Pruinosed dartlet
ASP	<i>Agriocnemis splendidissima</i>	Splendid dartlet
BBDRT	<i>Copera vittata</i>	Yellow bush dart
BBT	<i>Prodasineura verticalis</i>	Black bambootail
BDR	<i>Anax immaculifrons</i>	Blue darner
BMH	<i>Orthetrum glaucum</i>	Blue marsh hawk
BMT	<i>Tramea limbata</i>	Black marsh trotter
BSG	<i>Trithemis festiva</i>	Black stream glider
BTD	<i>Dysphaea ethela</i>	Black torrent dart
BTFGLY	<i>Vestalis apicalis</i>	Black-tipped forest glory
BTFH	<i>Orthetrum triangulare</i>	Black tipped forest hawk
BTGDR	<i>Anax guttatus</i>	Blue-tailed green darner
BTYSK	<i>Palpoleura sexmaculata</i>	Blue-tailed yellow skimmer
BULA	<i>Burmagomphus laidlawi</i>	
BwDR	<i>Gynacantha dravida</i>	Brown darner
CCT	<i>Ictinogomphus rapax</i>	Common clubtail
CHBEA	<i>Brachydiplax chalybea</i>	Rufous-backed marsh hawk
CHRYS	<i>Orthetrum chrysis</i>	Brown-backed marsh hawk
CHT	<i>Paragomphus lineatus</i>	Common hooktail
CMDRT	<i>Ceriagrion coromandelianum</i>	Coromandel marsh dart
CMG	<i>Trithemis aurora</i>	Crimson marsh glider
GOMCF	<i>Gomphidia sp</i>	
CORW	<i>Tholymis tillarga</i>	Coral-tailed cloud wing
CPW	<i>Rhyothemis variegata</i>	Common picture wing
CROC	<i>Hydrobasileus croceus</i>	Amber-winged marsh glider
CTMH	<i>Orthetrum pruinosum</i>	Crimson-tailed marsh hawk
CWFLY	<i>Vestalis gracilis</i>	Clear-winged forest glory
DJW	<i>Brachythemis contaminata</i>	Ditch Jewel
EPV	<i>Enallagma parvum</i>	Azure dartlet
ESP	<i>Lestes elatus</i>	Emerald spread wing
GDRT	<i>Ischnura aurora</i>	Golden dartlet

Species codes	Scientific name	Common name
GMH	<i>Orthetrum sabina</i>	Green marsh hawk
GOKO	<i>Gomphidia kodaguensis</i>	
GRGO	<i>Bradinopyga geminata</i>	Granite ghost
GSK	<i>Diplacodes trivialis</i>	Ground skimmer
INDO	<i>Indothemis carnatica</i>	Black marsh skimmer
LBMH	<i>Brachydiplax sobrina</i>	Little blue marsh hawk
LLMG	<i>Trithemis pallidinervis</i>	Long-legged marsh glider
LUZON	<i>Orthetrum luzonicum</i>	Tri-coloured marsh hawk
NCT	<i>Onychogomphus nilgiriensis</i>	Nilgiri claw tail
PDC	<i>Pseudagrion decorum</i>	Three-lined dart
PIDRT (AGRIO)	<i>Agriocnemis pygmaea</i>	Pygmy dartlet
PISK	<i>Tetrathemis platyptera</i>	Pygmy skimmer
PPSK	<i>Neurothemis tullia</i>	Pied paddy skimmer
PRT	<i>Protosticta gravelyi</i>	Pied reed tail
PSM	<i>Pseudagrion microcephalum</i>	Blue dart
PV	<i>Panatala flavescens</i>	Wandering glider
RHEL	<i>Libellago lineata</i>	River heliodor
RMH	<i>Crocothemis servilia</i>	Ruddy marsh skimmer
RMT	<i>Tramea basilaris</i>	Red marsh trotter
RUFA	<i>Rhodothemis rufa</i>	Rufous marsh glider
SFBDRT	<i>Pseudagrion rubriceps</i>	Pseudagrion rubriceps
SGDRT	<i>Ischnura senegalensis</i>	Senegal golden dart
SGLY	<i>Neurobasis chinensis</i>	Stream glory
SMF	<i>Aethriamanta brevipennis</i>	Scarlet marsh hawk
SRG	<i>Trithemis kirbyi</i>	Scarlet rock glider
SRH	<i>Onychothemis testacea</i>	Stellate river hawk
SRUBY	<i>Rhinocypha bisignata</i>	Stream ruby
TAEN	<i>Orthetrum taeniolatum</i>	Taeniolate marsh hawk
TRMT	<i>Acisoma panorpoides</i>	Trumpet tail
USIG	<i>Urothemis signata</i>	Greater crimson glider
YBDRT	<i>Copera marginipes</i>	Yellow bush dart
YTASK	<i>Potamarcha congener</i>	Yellow-tailed ashy skimmer

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ODONATES OF COIMBATORE DISTRICT, TAMIL NADU, INDIA

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Abstract: Odonates were surveyed in Coimbatore District from September 2012 to January 2016. The survey sites covered three major rivers—the Noyyal, Bhavani and Aliyar. Aquatic habitats such as forest streams, riverine sites, irrigational tanks and paddy fields were surveyed in the study. A total of 70 species of odonates were recorded in the survey, which brings the list of odonates in Coimbatore to 87 species. Eighteen species are first time records to the district. In this paper, we catalogue odonates and their distribution from the present survey and pre-existing records.

Keywords: Aliyar River, Bhavani River, Coimbatore, damselflies, dragonflies, Noyyal River.

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Author Details and Contribution: M. SUHIRTHA MUHIL is a PhD scholar in Salim Ali Centre for Ornithology and Natural History. All field studies, data collection and the preparation of the manuscript in the prescribed format was done by her. The work is part of her doctoral thesis. DR. P. PRAMOD is a Principal Scientist at Salim Ali Centre for Ornithology and Natural History and Head of the Nature Education department. The study was conceptualized and planned by him.

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INTRODUCTION

Freshwater ecosystems the world over are under tremendous anthropogenic pressure and there is an urgent need to assess the quality of these freshwater habitats. In biodiversity hotspots such as Western Ghats, which support numerous endemic taxa, freshwater resources are highly exploited. To assess and characterize freshwater habitats, bioindicators are used. Among the bioindicators of freshwater, odonates are known to be highly sensitive indicators of the habitat concerned (Clarke & Samways 1996; Samways & Steytler 1996; Subramanian 2009). Baseline data on the distribution of odonates provide valuable information on habitat specific species and the status and quality of aquatic systems.

Dragonflies and damselflies (Odonata) are known to have high diversity and endemism in the Western Ghats (Subramanian et al. 2011). Numerous studies on the odonates of Western Ghats have been published recently (Rangnekar et al. 2010; Kiran & Raju 2013; Verghese et al. 2014; Adarsh et al. 2015; Tiple & Koparde 2015); however, the studies on range extension (Das et al. 2013), species additions (Rangnekar et al. 2010; Emiliyamma et al. 2012, 2013; Rangnekar & Naik 2014) and new species description (Subramanian et al. 2013) confirm the need for extensive odonatological research required in the Western Ghats.

Surrounded by the Western Ghats, Coimbatore exhibits varied landscapes, vegetation and aquatic bodies suitable for a rich diversity of odonates. Odonates in this region were first documented by Fraser (1924, 1931, 1933, 1934, 1936) enlisting 48 species and by Ayyar & Ayyar (1933) adding six more species. Twenty-three species have been documented from the insect collection of Agricultural College and Research Institute, Coimbatore (Abraham 1959), of which two species were additional records after which, studies in the region (1999 onwards) have recorded: 22 species from the paddy fields of Coimbatore (Gunathilagaraj et al. 1999; Chitra et al. 2002; Arulprakash & Gunathilagaraj 2010b); 23 species from tanks (Arulprakash & Gunathilagaraj 1999; Karthika & Krishnaveni 2014); seven species from Bhavani River (Arulprakash & Gunathilagaraj 2010a) and seven species from other opportunistic observations (Arulprakash & Gunathilagaraj 2010b). These checklists provide an addition of 13 species to the district.

Odonata checklist from various forest reserves and wildlife sanctuaries adjoining Coimbatore has also been catalogued extensively—Silent Valley National Park (Rao & Lahiri 1972), Parambikulam (Emmiliyama &

Radhakrishnan 2000), Thattekad (Varghese et al. 2014), Chinnar Wildlife Sanctuary (Adarsh et al. 2015).

Published catalogues of odonates of Coimbatore cover limited habitats and areas of the district. Given the wide geographical extent of the district and its varied habitats, our aim was to catalogue odonates from various aquatic bodies in Coimbatore, covering forest streams, river, irrigational tanks, ponds and paddy fields. We have consolidated the number of species recorded in our survey and from previous existing literature. The distributions of species from various habitats are also provided.

STUDY AREA

Coimbatore District lies in the western part of Tamil Nadu state (10°13'4"–11°24'5"N and 76°39'25"–77°18'26"E). Many parts of the district lie in the leeward side of the Western Ghats (Fig. 1). The district is criss-crossed by the Palghat gap (a 30km-wide gap in the otherwise continuous mountain chain) dividing the hills into northern and southern sections. The northern section comprises the Siruvani-Vellingiri Hills; the Anaikatty Hills and Athikadavu Valley which skirts the lower elevations of the Nilgiris. The former hill range contributes to the Noyyal River basin and the latter two to the Bhavani River. The southern section comprises the high rising Anaimalai Hills from which the Aliyar River originates. In between these two sections of mountains lies the Palghat gap, a 30-km stretch of plain which tapers in gradient towards the west. The Aliyar River drains in the gap and adjoins many other tributaries flowing from the Anaimalais and the northern section of the hills to form the Ponnani River. The forested hilly terrains of Coimbatore District are covered by semi-evergreen, wet dry deciduous forest and in most parts by dry deciduous forest. While the plains of Coimbatore and the Palghat gap are predominantly agricultural landscapes.

The south-west monsoon provides copious rainfall (>800mm) to the higher slope of the northern and southern section of the mountains and the Palghat gap (Arun & Vijayan 2004; Rathod & Aruchamy 2010). The rest of the district receives scanty rainfall from the south-west monsoon and this region is supplemented with 600-800 mm rainfall by the north-east monsoon (Rathod & Aruchamy 2010). Rainfall in the higher reaches contributes to the seasonal river Noyyal and the irrigational tanks in the plains during the south-west monsoon.

Our study cover various aquatic habitats such as

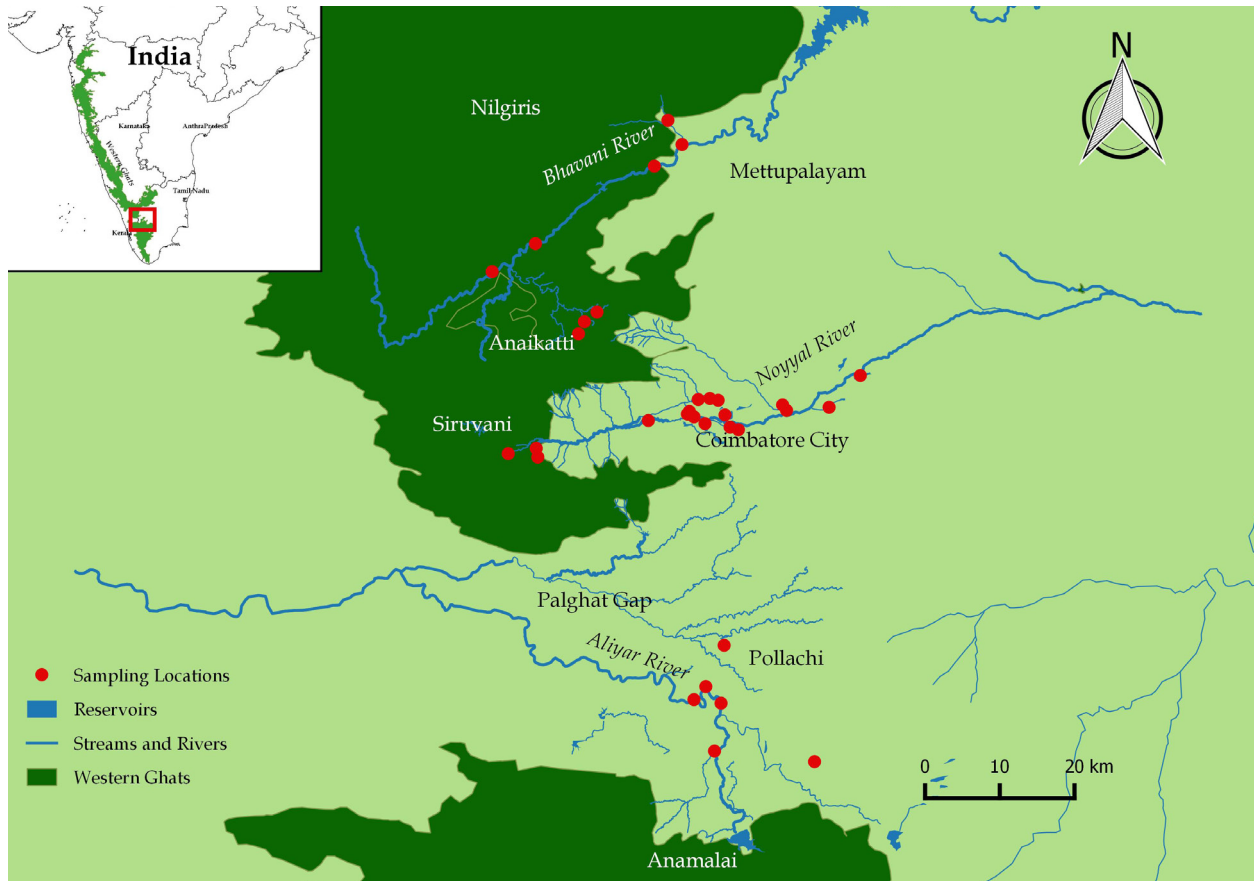


Figure 1. Study locations from the present survey.

forest streams; riverine sites; irrigational tanks and ponds and paddy fields across the Noyyal, Bhavani and Aliyar rivers.

METHODS

Our study was conducted from September 2012 to January 2016 across different aquatic bodies in Coimbatore District (Images 1–10). Adult dragonflies were surveyed between 09:00–16.00 hrs by direct search technique (Sutherland 1996). Opportunistic observations have also been included to the current list. The species were photographed using Lumix FZ 200 and identified with the help of standard field guides: Subramanian (2009), Nair (2011) and Fraser's Fauna of British India (1933–36). A total of 36 locations were surveyed (Table 1). We seasonally surveyed 24 sites with a frequency of 12 visits. The other sites were visited with a minimum frequency of one to a maximum of four visits. Previous records of odonates from this region are also included in the checklist (Table 2).

RESULTS AND DISCUSSION

We have recorded 70 species of odonates in our study, of which 18 species are first time records to the Coimbatore District making the list with 87 species, belonging to 58 genera and 12 families (Table 2). From the enlisted 87 species, there are 20 endemics (14 species and 6 subspecies level) of which 14 are endemic to the Western Ghats (10 species and 5 sub-species level) (Babu et al. 2013). Of the 70 species from the present survey, we recorded 14 endemics, eight of which are endemic to the Western Ghats. Recorded distribution of odonates shows that the highest number of species was recorded from forest streams (70), followed by river (52), tanks (37) and paddy fields (23) respectively (Fig 2). The most speciose family is Libellulidae (39), followed by Coenagrionidae (14) and Gomphidae (10) (Table 2).

In the present study, 18 species were recorded for the first time from Coimbatore District; however, most of these species have been recorded from various adjoining regions of Coimbatore—the Nilgiris, the Anaimalai and Palani hills (Fraser 1923, 1924, 1931,

Table 1. List of locations surveyed in the present study

Locations	Wetland type	Habitat and vegetation type	Altitude (m)	Co-ordinates
Bhavani River basin				
Kallar- tributary stream (not river)	FS	Between the Kallar-Jagganari slopes reserve forest, surrounded by dry deciduous forest at one end and areca nut groves on the other	379	11°20'15.0"N & 76°52'54.1"E
Bathrakaliamankovil	R	Riverine stretch surrounded by areca nut groves and other fields	315	11°17'37.6"N & 76°53'30.4"E
Vilamarathur	R	Riparian forest adjacent to areca nut groves	327	11°16'55.4"N & 76°51'54.9"E
Athikadavu	R	Riparian forest	449	11°12'50.82"N & 76°45'16.64"E
Chavadiyur	R	Riverine stretch surrounded by agricultural fields	486	11°09'23.2"N & 76°55'38.9"E
Chavadiyur- Mulli	R	Riparian forest on one side and agricultural fields on the other	481	11°09'52.27"N & 76°41'01.53"E
SACON, Anaikatty	FS	Seasonal stream; dry-deciduous forest	626	11°05'45.48"N & 76°46'46.32"E
Kondanur	FS	Seasonal stream; dry-deciduous forest	629	11°06'27.41"N & 76°47'37.27"E
Noyyal River basin				
Kovai Kuttralam waterfall	FS	Moist deciduous forest	550	10°56'19.79"N & 76°43'13.9"E
Nandankarai checkdam	FS	Open stream clears into a checkdam surrounded by teak plantations	496	10°56'00.32"N & 76°43'22.26"E
Siruvani checkpost	FS	Mixed deciduous forest and teak plantations	469	10°56'36.0"N & 76°43'13.9"E
Madhampatty	R	Seasonal river, surrounded by agricultural fields	429	10°58'38.0"N & 076°51'29.0"E
Perur	R	Seasonal river, surrounded by agricultural fields	416	10°58'45.1"N & 076°54'52.0"E
Somayampalayam tank	T	Seasonal tank surrounded by agricultural fields	463	11°02'43.71"N & 076°53'43.61"E
Perur big tank	T	Seasonal tank surrounded by agricultural fields	411	10°58'08.15"N & 076°55'51.35"E
Nagarajapuram tank1	T	Rural tank surrounded by agricultural fields	425	10°59'58.73"N & 076°54'31.26"E
Nagarajapuram tank2	T	Rural tank surrounded by agricultural fields	426	11°00'05.62"N & 076°55'13.38"E
Paddy Breeding station	T	Paddy of different stages throughout the year	421	10°59'42.3"N & 076°55'02.2"E
TNAU- Wetlands	T	Paddy of different stages throughout the year	421	11°00'10.8"N & 076°55'19.3"E
Vedapatty lake 1	T	Seasonal tank surrounded by areca nut groves and other agricultural fields	420	10°59'03.08"N & 076°54'18.60"E
Vedapatty lake 2	T	Seasonal tank surrounded by areca nut groves and agricultural fields	417	10°59'06.1"N & 076°54'23.0"E
Muthanankulam 1	T	Perennial urban tank, highly polluted	426	11°00'12.8"N & 076°55'55.8"E
Muthanankulam 2	T	Perennial urban tank, highly polluted	422	11°00'11.4"N & 076°55'38.9"E
Kuruchi lake 1	T	Urban seasonal tank	405	10°58'11.4"N & 076°57'27.7"E
Kuruchi lake 2	T	Urban seasonal tank	402	10°57'56.06"N & 076°58'09.29"E
Ukkadam tank	T	Perennial urban tank, highly polluted	409	10°57'56.06"N & 076°58'09.29"E
Valankulam tank	T	Perennial urban tank, highly polluted	407	10°59'28.87"N & 077°57'04.01"E
Singanallur lake 1	T	Perennial urban tank, highly polluted	390	10°59'50.49"N & 077°01'15.59"E
Singanallur lake 2	T	Perennial urban tank, highly polluted	391	10°59'08.20"N & 077°01'30.72"E
Sulur lake	T	Perennial semi-urban tank surrounded by agricultural fields	364	11°01'38.91"N & 077°06'34.36"E
Pallapalayam lake	T	Perennial tank surrounded by agricultural fields	384	10°59'23.77"N & 077°04'25.42"E
Aliyar River basin				
Anaimalai town	R	Open river, surrounded by Coconut groves	251	10°34'48.92"N & 076°56'19.69"E
Ambarampalayam	R	Open river, surrounded by Coconut groves	226	10°38'15.22"N & 076°56'47.97"E
Athupollachi	R	Open river, surrounded by Coconut groves	221	10°39'28.75"N & 076°55'44.41"E
Kaliapakoundenpudur	R	Open river, surrounded by Coconut groves	204	10°38'15.22"N & 076°56'47.97"E
Uthukuli pond	T	Perennial tank surrounded by coconut groves- highly polluted	258	10°39'24.55"N & 076°58'37.82"E
Palayur pond	T	Seasonal rural pond	306	10°35'53.66"N & 077°03'18.16"E
D. Kalipalayam Wells	T	Seasonal rural pond	231	10°41'36.99"N & 076°57'04.01"E

FS - Forest Streams; R - Rivers; T - Tanks and Ponds



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Image 1. Muthanankulam, Coimbatore - Urban perennial tank



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Image 2. Singanallur Lake, Coimbatore - Urban perennial tank



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Image 3. Vedapatty, Coimbatore - Rural seasonal tank



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Image 4. Wetland Paddy fields, TNAU, Coimbatore



© M. Suirtha Muhil

Image 5. Noyyal River - Madhampatti, Coimbatore



© M. Suirtha Muhil

Image 6. Aliyar River - Athupollachi, Pollachi



Image 7. Bhavani River between Chavadiyur and Mulli, Athikadavu



Image 8. Anaikatty forest - Kondanur seasonal stream, Anaikatty



Image 9. Kallar tributary forest stream, Mettupalayam



Image 10. Nandankarai checkdam of Siruvani, Coimbatore

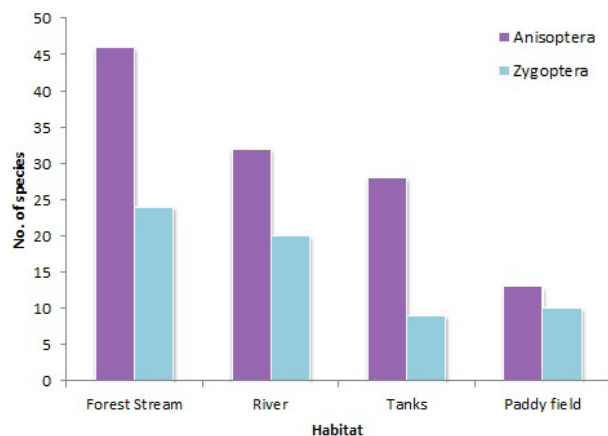


Figure 2. Odonate species richness in different aquatic habitats of Coimbatore

1933, 1934, 1936; Rao & Lahiri 1972; Verghese et al. 2014; Adarsh et al. 2015). Of the first time records, we were unable to authenticate the record of one species, belonging to the genus *Gomphidia*, which was sighted twice in the Bhavani river near Mettupalayam. The damselfly, *Euphaea dispar*, known for its high elevational distribution (900–1,500 m) (Kakkasery 2011) was recorded in the fast flowing cascade in Siruvani forest, Coimbatore (550m). Fraser (1924) attributes the presence of *E. dispar* at lower elevations due to its competition with *E. fraseri*, the latter driving the former to higher elevations. In the absence of *E. fraseri*, the species is known to occur in lower elevations. *Indothemis carnatica*, a Near Threatened IUCN Red list species (Dow 2009) was recorded in streams and tanks in the Siruvani and Anaikatty forests of Coimbatore. The IUCN cites that this species could be under recorded and



Image 11. *Anaciaeschna jaspidea*



Image 12. *Anax immaculifrons*



Image 13. *Gynacantha dravida*



Image 14. *Burmagomphus laidlawi*



Image 15. *Ictinogomphus rapax*



Image 16. *Onychogomphus nilgiriensis*



Image 17. *Paragomphus lineatus*



Image 18. *Acisoma panorpoides*



Image 19. *Aethriamanta brevipennis*



Image 20. *Brachydiplax chalybea*



Image 21. *Brachydiplax sobrina*



Image 22. *Bradinopyga geminata*

Table 2. List of dragonflies and damselflies recorded in Coimbatore

Family / Common name	Habitat	Records of distribution	Recorded by
Aeshnidae			
<i>Anaciaeschna jaspidea</i> Burmeister, 1839	T	Crepuscular species also recorded in the urban areas to light source	MP
<i>Anax guttatus</i> Burmeister, 1839	F,R,T	Throughout Coimbatore	AG ³ , MP
<i>Anax immaculifrons</i> Rambur, 1842	F,T	Throughout Coimbatore	TK, AB, MP
<i>Anax parthenope</i> Selys, 1839	T	Crepuscular species recorded in tanks	F ³
<i>Gynacantha dravida</i> Leitnick, 1960	F	Crepuscular species also recorded in the urban areas to light source	F ^{2,3} , AG ³ , MP
<i>Hemianax ephippiger</i> Burmeister, 1839	P	Paddy field	TK, AB, AG ³
Gomphidae			
<i>Asiagomphus nilgircus</i> Laidlaw, 1922**	R	Bhavani River	F ³
<i>Burmogomphus laidlawi</i> Fraser, 1924**	R	Bhavani River	F ³ , MP
<i>Gomphidia kodaguensis</i> Fraser, 1923**	F	Boluvampatti Forest	F ² , MP
<i>Gomphidia</i> sp (cf)	R	Bhavani River	MP
<i>Heliogomphus promelas</i> Selys, 1873**	F	Boluvampatti Forest	F ³
<i>Ictinogomphus rapax</i> Rambur, 1842	F,R,T	Throughout Coimbatore	F ² , TK, AB, AG ² , MP
<i>Megalogomphus superbus</i> Fraser, 1931**	F	Boluvampatti Forest	F ²
<i>Microgomphus souteri</i> Fraser, 1924**	F	Boluvampatti Forest	F ²
<i>Onychogomphus nilgiriensis</i> Fraser 1922**	F,R	Boluvampatti Forest, Bhavani River	F ³ , MP
<i>Paragomphus lineatus</i> Selys, 1850	F	Anaikatty Forest, Kallar, Boluvampatti Forest	F ³ , MP
Libellulidae			
<i>Acisoma panorpoides</i> Rambur, 1842	F,R,T,P	Forest streams, rivers, rural tanks and paddy fields	AG ³ , MP
<i>Aethriamanta brevipennis</i> Rambur, 1842	F	Boluvampatti Forest	MP
<i>Brachydiplax chalybea</i> Brauer, 1868	R,T	River rural and urban tanks	MP
<i>Brachydiplax sobrina</i> Rambur, 1842	R,T	River and tanks	MP
<i>Brachythemis contaminata</i> Fabricius, 1793	F,R,T,P	Throughout Coimbatore	AB,G, AG ^{2,3} , MP
<i>Bradinopyga geminata</i> Rambur, 1842	F,R,T	Throughout Coimbatore	F ¹ , K, AG ³ , MP
<i>Crocothemis servilia</i> Drury, 1770	F,R,T	Throughout Coimbatore	TK, AB, G, AG ^{1,2,3} , MP
<i>Diplacodes nebulosa</i> Fabricius, 1793	F	Boluvampatti Forest	MP

Family / Common name	Habitat	Records of distribution	Recorded by
<i>Diplacodes trivialis</i> Rambur, 1842	F,R,T,P	Throughout Coimbatore	F ² , TK, AB, G, AG ^{1,2,3} , MP
<i>Hydrobasileus croceus</i> Brauer, 1867	F,T	Boluvampatti Forest and rural wetlands	F ³ , MP
<i>Indothemis carnatica</i> Fabricius, 1798	F	Boluvampatti Forest, Anaikatty Forest	MP
<i>Lathrecista asiatica</i> Fabricius, 1798	F,T	Forest stream and rural ponds	MP
<i>Macrodiplox cora</i> , Brauer, 1867	F,R,T	Throughout Coimbatore	F ³
<i>Neurothemis fulvia</i> Drury, 1773		Exact location of record unknown	TK, AB
<i>Neurothemis tullia</i> Drury, 1723	R, T	Aliyar River	F ¹ , TK, AB, G, AG ² , MP
<i>Onychothemis testacea</i> Ris, 1912	R	Aliyar and Bhavani River	F ² , MP
<i>Orthetrum chrysis</i> Selys, 1891	F,R,P	All river and forested streams; also noted in rice fields	G, AG ³ , MP
<i>Orthetrum glaucum</i> Brauer, 1865	F,R,T	Forest streams, rivers and rural tanks	MP
<i>Orthetrum luzonicum</i> Brauer, 1868	F,R	All river and forested streams	F ³ , MP
<i>Orthetrum pruinatum</i> Rambur, 1842	F,R	All river and forested streams	F ² , MP
<i>Orthetrum sabina</i> Drury, 1770	F,R,T,P	All aquatic bodies	F ² , TK, AB, G, AG ^{1,2,3} , MP
<i>Orthetrum taeniolatum</i> Schneider, 1845	F,R	All river and forested streams	F ² , MP
<i>Orthetrum triangulare</i> Selys, 1878	F	Anaikatty and Boluvampatti Forest	MP
<i>Palpoleura sexmaculata</i> Fabricius, 1787	F	Boluvampatti forest	MP
<i>Panatala flavescens</i> Fabricius, 1798	F,R,T,P	Throughout Coimbatore	F ² , TK, AB, G, AG ^{2,3} , MP
<i>Potamarcha congener</i> Rambur, 1842	F,R,T,P	Throughout Coimbatore	AG ^{2,3} , MP
<i>Rhodothemis rufa</i> Rambur, 1842	F,R,T	Forest streams, rivers and rural tanks	AG ² , MP
<i>Rhyothemis variegata</i> Linnaeus, 1763	F,R,T	Throughout Coimbatore	AB, MP
<i>Tetrathemis platyptera</i> Selys, 1878	F	Anaikatty Forest	F ² , MP
<i>Tholymis tillarga</i> Fabricius, 1798	F,T,P	Throughout Coimbatore	F ² , TK, AB, AG ^{2,3} , MP
<i>Tramea basilaris</i> Kirby, 1889	F,T	Throughout Coimbatore	F ² , TK, AB, G, AG ^{2,3} , MP
<i>Tramea limbata</i> Rambur, 1842	F,R,T,P	All aquatic bodies	F ² , TK, AB, AG ^{2,3} , MP
<i>Trithemis aurora</i> Burmeister, 1839	F,R,P	All river and forested streams; also recorded in rice fields	F ² , TK, AB, G, AG ^{2,3} , MP

Family / Common name	Habitat	Records of distribution	Recorded by
<i>Trithemis festiva</i> Rambur, 1842	F,R	All river and forested streams	F ² , MP
<i>Trithemis kirbyi</i> Selys, 1891	F	Anaikatty Forest	F ³ , MP
<i>Trithemis pallidinervis</i> Kirby, 1889	F,R,T,P	Throughout Coimbatore	F ² , AG ² , MP
<i>Urothemis signata</i> Rambur, 1842	F,R,T,P	All aquatic bodies	AG ³ , MP
<i>Zygonyx iris malabarica</i> Selys 1869**	F	Kovai Kuttralam falls in Boluvampatti Forest	AG ³ , MP
<i>Zyxomma petiolatum</i> Rambur, 1842	F,R,T	Crepuscular species recorded to light source	MP
Macromiidae			
<i>Epophthalmia vittata</i> Burmeister, 1839*	F	Walayar Forest, Coimbatore	F ³
<i>Epophthalmia frontalis</i> Selys, 1871**	F	Walayar Forest ; Light Source	F ³ , AG ³
<i>Macromia cingulata</i> Rambur, 1842		Coimbatore district	F ³
Calopterygidae			
<i>Neurobasis chinensis</i> Linnaeus, 1758	F,R	All river and forested streams	F ² , MP
<i>Vestalis apicalis</i> Rambur, 1873**	F,R	All river and forested streams	F ² , TK, AG ³ , MP
<i>Vestalis gracilis</i> Rambur, 1842*	F,R	Boluvampatti Forest, Aliyar and Bhavani River	F ² , TK, AG ³ , MP
Chlorocyphidae			
<i>Libellago lineata</i> Burmeister, 1839	F,R	All river and forested streams	F ² , AG ¹ , MP
<i>Rhinocypha bisignata</i> Selys, 1853*	F,R	All river and forested streams	F ² , AB, AG ¹ , MP
Coenagrionidae			
<i>Aciagrion occidentale</i> Laidlaw, 1919	F	Boluvampatti forest	F ²
<i>Agriocnemis femina</i> Brauer, 1868	F,R,T	All aquatic bodies	MP
<i>Agriocnemis pygmaea</i> Rambur, 1842	F,R,T,P	All aquatic bodies	F ² , G, AG ^{2,3} , MP
<i>Agriocnemis splendidissima</i> Laidlaw 1919*	F,R	Boluvampatti forest and Bhavani River	MP
<i>Argiocnemis rubescens</i> Selys, 1877	P	Paddy fields	G
<i>Coeragrion cerinorubellum</i> Brauer, 1865	P	Paddy fields	G

Family / Common name	Habitat	Records of distribution	Recorded by
<i>Ceriagrion coromandelianum</i> Fabricius, 1798	F,R,T,P	All aquatic bodies	F ² , G, AG ^{2,3} , MP
<i>Enallagma parvum</i> Selys, 1876	F	Boluvampatti Forest	MP
<i>Ischnura aurora</i> Brauer, 1865	F,R,T,P	All aquatic bodies	F ² , AB, G, AG ^{2,3} , MP
<i>Ischnura senegalensis</i> Rambur, 1842	F,R,T,P	Tanks and ponds	G, AG ^{2,3} , MP
<i>Pseudagrion decorum</i> Rambur, 1842	F,R,T,P	All aquatic bodies	TK, AG ² , MP
<i>Pseudagrion indicum</i> Fraser, 1924**	F	Boluvampatti forest	MP
<i>Pseudagrion microcephalum</i> Rambur, 1842	F,R,T,P	All aquatic bodies	AG ² , MP
<i>Pseudagrion rubriceps</i> Selys, 1876	F,R,T	Forest streams, rivers and rural tanks	F ² , MP
Platystictidae			
<i>Protosticta gravelyi</i> Laidlaw, 1915*	R	Bhavani River	F ² , MP
<i>Protosticta sanguinostigma</i> Fraser, 1922*	F	Mettupalayam Ghat	F ³
Euphaeidae			
<i>Dysphaea ethela</i> Fraser, 1924*	R	Bhavani River	MP
<i>Euphaea dispar</i> Rambur, 1842**	F	Kovai Kuttralam falls in Boluvampatti Forest	MP
Lestidae			
<i>Lestes elatus</i> Hagen in Selys, 1862	F,T,P	Tanks, Paddy fields and Forested areas	AG ^{2,3} , MP
<i>Lestes viridulus</i> Rambur, 1842	P	Paddy fields of Coimbatore	TK, G
Platynemididae			
<i>Copera marginipes</i> Rambur, 1842	F,R	All river and forested streams	F ² , MP
<i>Copera vittata deccanensis</i> Laidlaw 1917*	F,R	All river and forested streams	AG ¹ , MP
Protoneuridae			
<i>Caconeura t-coerulea</i> Fraser, 1931**	F	Boluvampatti Forest	F ³
<i>Prodasineura verticalis</i> Selys, 1860**	F,R	Bhavani, Noyyal and Aliyar river	F ² ,AG ¹ , MP

Record references: F¹ - Fraser 1924; F² - Fraser 1931; TK - Ayyar & Ayyar 1933; F³ - Fraser - (1933-36); AB - Abraham 1959; G - Gunathilagaraj et al 1999; AG¹ - Arulprakash & Gunathilagaraj 2009; AG² - Arulprakash & Gunathilagaraj 2010a; AG³ - Arulprakash & Gunathilagaraj 2010b; MP- Muhil & Pramod (Present survey).

* Endemic to India; ** Endemic to Western Ghats; F - Forest Streams; R - Rivers; T - Tanks and Ponds; P - Paddy fields.



Image 23. *Crocothemis servilia*



Image 24. *Diplacodes trivialis*



Image 25. *Lathrecista asiatica* female



Image 26. *Neurothemis tullia*



Image 27. *Onychothemis testacea*



Image 28. *Orthetrum luzonicum*



Image 29. *Orthetrum chrysis*



Image 30. *Orthetrum glaucum*



Image 31. *Orthetrum pruinosum*



Image 32. *Orthetrum taeniolatum* female



Image 33. *Potamarcha congener*



Image 34. *Rhodothemis rufa*



Image 35. *Rhyothemis variegata*



Image 36. *Tetrathemis platyptera*



Image 37. *Tramea basilaris*



Image 38. *Trithemis aurora*



Image 39. *Trithemis festiva*



Image 40. *Trithemis kirbyi*



Image 41. *Trithemis pallidinervis*



Image 42. *Urothemis signata* female



Image 43. *Neurobasis chinensis*



Image 46. *Libellago lineata*



Image 44. *Vestalis apicalis*



Image 45. *Vestalis gracilis*



Image 47. *Rhinocypha bisignata*



Image 48. *Agriocnemis splendidissima*



Image 49. *Agriocnemis femina*



Image 50. *Agriocnemis pygmaea*



Image 51. *Ceriagrion coromandelianum*



Image 52. *Ischnura aurora*



Image 54. *Pseudagrion decorum*



Image 56. *Pseudagrion microcephalum*



Image 53. *Ischnura senegalensis*



Image 55. *Pseudagrion indicum*



Image 60. *Lestes elatus*



Image 57. *Pseudagrion rubriceps*



Image 58. *Dysphaea ethela*



Image 59. *Euphaea dispar*



Image 61. *Copera marginipes*

Image 62. *Copera vittata*Image 63. *Prodasineura verticalis*

its population size uncertain (Dow 2009).

Species like *Vestalis apicalis* and *V. gracilis* which are known only from forest and riverine areas in our survey have been observed far inland in the Tamil Nadu Agricultural University Campus (Arulprakash & Gunathilagaraj 2010b); the authors suggest that these stream dependent species spread far inland when aestivating. Similarly, *Trithemis aurora* a species predominantly found in streams and rivers are occasionally observed in paddy fields (Arulprakash & Gunathilagaraj 2010b).

Of the 69 species previously recorded from the region, 16 species were not observed during the study period (Fraser 1931, 1933, 1934, 1936; Ayyar & Ayyar 1933; Gunathilagaraj et al. 1999; Arulprakash & Gunathilagaraj 2010b). Some of the species, which Fraser had observed in the 1930s but were not observed in the present survey include *Asiogomphus nilgiricus*, *Heliogomphus promelus*, *Megalogomphus superbus*, *Microgomphus souteri*, *Macromia cingulata*, *Macrodiplax cora*, *Protosticta sanguinostigma*, *Caconeura t-coerulea* (Fraser 1931, 1933, 1934, 1936). The species *Megalogomphus superbus* recorded in the Coimbatore forest and *Caconeura t-coerulea* in the Mettupalayam ghats and Nilgiris remain to be the only record of these species (Fraser 1933). *Macrodiplax cora* a species recorded mostly in coastal areas and occasionally inland was found nearly in every bush in Coimbatore District by Fraser (1936). However this species was not recorded in over three years of our study.

In the present study, we have attempted to cover a wide range of aquatic habitats in the district. Our survey however, did not cover the Anaimalai hills which lies in the southern part of the district. Though earlier

records are available (Fraser 1931), we were not able to demarcate species distribution records between the wide range of the Anaimalai and Mudi Hills, hence they are not presented here. Moreover, the Anaimalai ranges as a whole have a rich odonate entity, which at present requires a rigorous assessment. Similarly, an extensive list of odonates has been recorded from the Kallar and Buraliyar rivers (tributaries of Bhavani, Nilgiri District). Some of the species recorded here include, *Idionyx buraliyaarensis*, *Idionyx nilgiriensis* (Fraser, 1926), *Euphaea fraseri* (Fraser, 1931; Abraham, 1959), *Onychogomphus striatus*, *Hylaeothemis indica* (Fraser, 1931).

The Palghat gap in our study area is known to be a geographic barrier for many taxa, in the mountains either side of the gap (Daniels 1992; Robin et al. 2010; Klaus et al. 2014). The same status was established in high altitude odonate assemblage study by Fraser (1923), who indicated that the gap distinctly divides the odonate faunal group into northern and southern groups. Fraser (1931) also reported that the direction of flow of rivers in this region could influence the segregation of odonates into eastern and western groups. Considering this, studies can be intensified in the rivers flowing east and west of Coimbatore District and also in the high altitudes to establish the above observations. The consolidated list of 87 species, indicate the rich odonate diversity in Coimbatore. More species can be expected from this region; given the fact that the region supports varied landscapes and drainages. This region along with core areas of Siruvani hills may hold additional species, which needs to be revisited. Along with the knowledge in the distributional range of species, an understanding of species and their suitable habitats will help in the conservation implication of fresh water sources.

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