Study of Terrestrial Birds with special reference to insects as their food base around three reservoirs in Central Gujarat

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Submitted by

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STUDY OF TERRESTRIAL BIRDS WITH SPECIAL REFERENCE TO INSECTS AS THEIR FOOD BASE AROUND THREE RESERVOIRS IN CENTRAL GUJARAT

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<u>CERTIFICATE</u>

This is to certify that the thesis entitled "**Study of Terrestrial birds with special reference to insects as their food base around three reservoirs in Central Gujarat**" submitted by **Ms. Nirjara Gandhi** for the degree of Doctor of Philosophy has been carried out under my guidance in the Department of Zoology, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara. The matter presented in this thesis incorporates the results of investigation of the independent research carried out by the researcher herself. The matter contained in this thesis has not been submitted elsewhere for the award of any other degree.

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3rd May 2012

DECLARATION

I hereby declare that the entire work embodied in this thesis has been carried out by me under the supervision and giudance of Dr. Geeta Padate and to the best of my knowledge no part of the thesis has been submitted for any degree or diploma to this university or any other university or Institutes in India or Abroad.

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A THESIS SUBMITTED

TO

THE MAHARAJA SAYAJIRAO UNIVERSITY OF BARODA

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN ZOOLOGY

DEDICATED

TO

MY

PARENTS

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CONTENT

INTRODUCTION

India due to its tropical location and influence of the monsoon winds has tropical monsoon type of climate which maximally influences the economy. Nearly 70% population of the country lives in rural area and earns their living by agriculture. For the sustenance of the agriculture, water is essential. In the monsoon type of climate of India, rainfall being a seasonal phenomenon, precipitation is observed only during certain part of the year *i.e.* June to September in the western parts and November to December in the eastern part of the country. Hence, to combat the water needs in dry seasons of the year, construction of reservoirs becomes essential. In many areas, depressions on the surface of earth are dammed so that the rain water can accumulate naturally resulting in the formation of reservoirs which can supply water during dry conditions. This stored water is used for irrigation, livestock farming, fishing and many other human utilities.

According to the Biogeographic classification of India, major part of Gujarat falls in the arid and Semi arid Zones. Central Gujarat where the present study was carried out comes under the semi arid zone of the state where several reservoirs have been built over the century to fulfill the water requirements of the residents living in the vicinity. Most of these reservoirs were built for the purpose of Irrigation.

Water being the basic necessity of life, wherever and whenever water is available life comes into existence. The shallow areas of these reservoirs, the transitional zone between land and water, saturated with water, have developed in to valuable ecosystems - the Wetlands. Ramsar Convention defines wetlands as “area of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water; the depth of which at low tide does not exceed six meters”. These are considered as one of the most diverse aquatic ecosystem supporting a variety of flora and fauna (Ramachandra *et al.,* 2002). These ecosystems, linking the terrestrial and aquatic systems, play a significant and sensitive ecological role especially in terms of the bio-geo-chemical cycling of various nutrients (Pandey *et al.*, 2004), and are considered as the “Kidneys of the landscapes” (Mitsch and Gooselink, 1986). Their value is increasing as they contribute to the health of the environment.

After the implementation of the Ramsar convention, this much neglected ecosystems - the wetlands, started getting due importance. Ramsar Convention, adopted in the year 1971, rated the water bodies according to the waterfowl density it supported. As water birds form one of the major group supported by the wetlands, the density and diversity of water fowls supported by many major wetlands have been documented. However, in recent years Ramsar convention puts more emphasis on the sustainable use of the wetland ecosystem and hence various parameters like the physicochemical properties of the water present along with the pollution status and the wise use of the resources available in the ecosystem has also become important.

Besides Ramsar Convention, the Convention on Biodiversity signed at Rio De Janeiro, Brazil in 1992 aims on the documentation of the Biodiversity present from the grass root level to the larger ecosystem level. Under the concept of conservation of Biodiversity, conservation of the Ecosystem has gained momentum rather than conservation of a species. The Biodiversity Earth Summit has now reached from the National to State level where the identification of the species at local level is a major concern.

Hence considering the two Convention, the present study aims to document some biodiversity (terrestrial birds and the insects) around three reservoirs in the semi arid zone of Central Gujarat where waterfowl have already been documented with the Physico-chemical characteristics of water and density and diversity of lower groups like Plankton and mollusc (Deshkar, 2008; Rathod, 2009). In continuation of these studies present work is expected to be useful in the preparing the inventories of the biodiversity at the local level and also in designing the management planning for these reservoirs.

Wetlands play a significant role in maintaining the ecological integrity of a region. Although they cover less than 9% of the global land area, they provide a disproportionately wide range of functions, including support for biodiversity, improvement of water quality , flood abatement, and carbon sequestration (Zedler and Kercher, 2005).

Large variety of flora and fauna are supported by Wetlands. Wetland birds are important components in the wetland ecosystem. As the definition of Wetlands says transitional zone between land and water, the terrestrial ecosystems around the wetlands should also be given importance. Though, these terrestrial habitats (i.e. Landscape around the wetlands) are also important areas supporting various terrestrial fauna, these are comparatively least studied habitats. It is easy to observe more visible water birds having affinity to water at a wetland. However, large number of organisms including terrestrial birds that colonize the surroundings of the water bodies are neglected at all instances. All the organisms present in an ecosystem has equal importance as the absence of one has the potential to disturb the whole food web and may lead to breakdown of the natural ecosystem.

The shallow zones of wetlands are highly productive supporting a variety of submergent and emergent vegetation along with a variety of animals. Though this vegetation harbor a variety of aquatic fauna, a large number of the terrestrial fauna are also found around them. The natural beauty and diversity of these animals and plants make a wetland aesthetically captivating (Tam and Wong, 2000). The abundant plant and animal diversity of wetlands derives from the fact that they are neither fully aquatic nor fully terrestrial systems (Wrubleski and Ross, 2011). As this habitat is vulnerable to habitat loss due to increasing pollution and anthropogenic activities, regular monitoring of this ecosystems is also necessary.

As said earlier, Deshkar (2008) and Rathod (2009) initiated the documentation of plankton, molluscs and waterfowl diversity and density and their co-relation with the Physico-chemical parameters at the three reservoirs. However, terrestrial bird and the insect diversity around these reservoirs could not be documented. Hence, the present study was initiated to document the terrestrial bird and the insect diversity around the three reservoirs to obtain an overall seasonal account of these two groups and a step further in documenting biodiversity of the area.

Any study conducted around the wetland ecosystem focuses mainly on the water quality, Plankton, plants, *etc*. and the larger organisms like Birds which are easily visible; however, terrestrial birds are quite often neglected. These species are present around wetlands, as food resources in the form of invertebrates are available in plenty in the area. Although invertebrate fauna is much more diverse than the vertebrate fauna, it is frequently overlooked due to their smaller size and the efforts required in their collection and identification. Terrestrial invertebrates present around the wetland comprise one of the most important components occupying these environments along with their larvae, many of which contribute to the aquatic fauna too.

Various organisms present in the vicinity of wetlands also play important role in the maintenance of the balance of these ecosystems. One such group is that of Terrestrial birds observed in large numbers around these fragile ecosystems. Due to their frequently secretive nature, difficulty faced to locate them and speed of their movement, they are often overlooked (Brown and Collier, 2004). These are facultative species supported by wetlands along with certain insects which utilize the habitat at some stage of their life. Thus, the species richness at a wetland is always high (Weller and Spatcher, 1965).

Documenting biodiversity with its interdependency on various components of the food web is essential. Birds are one of the highly mobile and the most charismatic group of Vertebrates receiving highest attention as well as protection. They are also considered as important indicators of the health of an ecosystem (Koskimies, 1989) as they react rapidly to the changes in the habitat. They are able to colonize in a wide variety of habitats. Despite the fact that bird populations may not provide an ideal ‘early warning system’ of environmental deterioration (Temple and Wiens, 1989), changes in the bird numbers, species diversity and composition, and community structure in a particular habitat can provide indication of modification in the habitat in which they live. Bird population monitoring therefore provides a useful means of evaluating habitat conservation efforts and the effects of management interventions (Ntiamoa-Baidu *et al*., 2000). Birds are most conspicuous and significant components of freshwater wetland ecosystems and their presence or absence indicate the ecological conditions of that particular area (Rajpar and Zakaria, 2011). Aves can play a key role in a global monitoring system (Donald *et al*., 2001) and changes in their distribution and behavioral characteristics can be associated with an early indication of the impact of global warming and habitat modification (Balfour, 2007).

Terrestrial birds colonize wide variety of habitats ranging from the forest to mountains, rural to urban and tropical to temperate. Terrestrial birds can be broadly divided into specialist species and generalist species according to their capacity to adapt in different sets of conditions. Most of the species are specialist which require particular set of environmental conditions and hence have a restricted range whereas others are the generalist species able to adapt to all types of environmental conditions and survive in wide range of habitats (Teer, 1995). These can also be categorized as Exploiter of habitat, Adaptor to a habitat and Native species (Kark *et al*., 2007). The exploiters are the species that have so well adapted to the environmental changes that they are able to exploit the resources available to the fullest while the adaptors gradually adapt to the habitat and thrive therein. Native species are the species that have difficulties in adjusting to the changing situations and withdraw to colonize in other favourable habitats.

As far as distribution of organism is concerned it is often limited by availability and accessibility of food and water. However, the type, size and quantity of food influence the distribution of organisms that depend on Wetland (Murakami, 2002; Bolduc and Afton, 2004). Availability of food is the major factor for the occurrence of a species in a particular habitat. Aves are ranked as the top predator in the wetland trophic cascades. Birds require different types of food at different stages of their life. Many species of birds occupying higher position in the food chain depend on the invertebrates, in the early stages of life. The abundance and distribution of prey base affects the fitness of individual birds by producing temporal changes in the foraging behaviour and hence the structure of avian community (Murakami, 2002). Of the invertebrates serving as the primary food source for the terrestrial birds, arthropods are the most preferred groups (Rosenberg *et al.*, 1991; Gray, 1993). There are many species of birds that are insectivorous feeding solely on insects, while there are groups like Graminivores, Nectarivores, Frugivores, Omnivores and many Carnivores that feed their chicks with insects which are rich in protein content (Immelmann, 1971). The groups feeding on grains, fruits and various animal matters also get sufficient food supply around the reservoirs and hence they colonize the area. These are also important biotic components of the wetland ecosystem (Weller, 1999).

Insectivorous birds have been shown to have direct effects on abundance of herbivorous arthropods (Strong *et al.,* 2000). The type of insect consumed forms the most important resource axes with ecological separation. This is achieved by many insectivores (Martin and Stiles, 1992; Cucco *et al.,* 1993). Habitat change has been implicated to decline in number of species across the world, but the loss of the foraging habitats and associated prey species are considered as the major cause of such declines (Lourie and Tompkins, 2000). As predators of insects, birds stand supreme among all the vertebrates because of their high mobility and ability to congregate quickly in large numbers when sudden outbreaks of insect pests occur (Dhindsa and Saini, 1994). Hence, these are considered as the best pest controllers in the agricultural fields (Asokan *et al.,* 2009) too.

Further insects provide an important source of protein and several essential amino acids for gonadal development and egg laying by birds. They also form a rich source of lipids and energy (Driver *et al.* 1976; Afton and Ankney, 1991). Insects provide an important food resource for many birds (Sealy, 1980; Guinan and Sealy, 1987).

Taxonomically, Insects are the most varied group of invertebrates consisting of nearly 70% of the total invertebrate fauna present on the planet earth. These have adapted to wide range of habitats and are found in every possible habitat on the planet. The success of insects is attributed largely to the evolution of flight, which has facilitated their dispersal, escape from predators and access to food and adaptation to optimal environmental conditions (Ragaei and Allam, 1978). Insects are also particularly useful in the evaluation of landscapes for biological conservation (Kim, 1993; Samways, 1994).

Wetland food chain has a very special position for the insect diversity. Large number of insect groups occurs in and around wetlands. There are many insects that require water at some stages of their life and hence colonize near a water body. The most prominent among these are the Odonates. As their larvae are aquatic, adults have to lay eggs on the water surface and hence prefer to remain in the vicinity of the water bodies. Another group of insects with aquatic larvae is the Dipterans. Other water dependent insects include some of the predatory aquatic bugs and aquatic beetles. The members of orders Odonata, Orthoptera, Dicytoptera, Isoptera, Hemiptera, Coleoptera, Diptera Lepidoptera and Hymenoptera are found in the surrounding habitats of wetlands including scrublands and agricultural fields. Hence in the present study, with density and diversity of terrestrial birds, the density and diversity of various insect biotas is also studied.

Among the various insect orders studied, Odonata is the most popular ‘flagship’ group (Hawking and New, 2002). Odonates play an important role in the aquatic environments, equal to the role played by the butterflies in terrestrial environments (Hawking and New, 2002). Both larvae and adults of Odonates (dragonflies—Anisoptera; damselflies—Zygoptera) act as the upper-level predators in the wetlands, hence are also considered bio-indicators for wetland quality (Clausnitzer and Jödicke, 2004). Their nymphs feed on the various dipteran larvae present in the water and hence reduce the numbers of the mosquitoes which are vector for many human diseases. They in turn serve as the prey base for large number of fishes and other aquatic organisms playing an important role in the aquatic food chain. The adults are predators in nature and feed on wide variety of flying insects like dipterans, ephemeropterans, neuropterans and small lepidopterans and make good prey for several insectivorous birds present in the area.

Orthoptera that includes the Grasshoppers and Crickets are generalist herbivores with low mobility (Marini *et al.*, 2009). They are terrestrial and prefer different types of grasses. Many types of grasshoppers are found in the aquatic weeds and so they may be observed around the reservoirs. They also form prey base for a large number of ground feeding insectivorous birds.

Dicytoptera, consisting of the Cockroaches and Mantis, is the order with two main families one consisting of the household pests the cockroaches while the other the predatory Praying Mantis. Praying mantis predates on various harmful organisms and hence is important from the ecological point of view.

Isoptera consists of various types of termites which have colonial organization. They feed on a wide variety of soil and wood particles. These are basically harmful organisms in the urban areas but in natural habitats they are involved in soil turnover as well as serve as food for many ground feeding insectivores birds.

Hemipterans consist of aquatic and terrestrial bugs. These basically consist of three groups of insects, one the predatory bugs that include the aquatic bugs and the terrestrial bugs. Of these aquatic bugs feed on various harmful organisms in the water and serve as important fish food, bio-indicators, predators and bio-control agents while the terrestrial predacious bugs reduce the number of agricultural pests and act as biological controller of pests (Das and Gupta, 2010). Second group includes the Plant sap suckers that are herbivorous and are known to have a mutualistic relationship with Ants. Third group of Hemipteran insects are the major agricultural pest themselves causing damage to various agricultural as well as ornamental plants. The terrestrial bugs also form prey base for the arboreal insectivorous birds.

Coleoptera the next order is the biggest order of class Insecta consisting nearly ¼ of all known insects. These are adapted to live in varied habitats except Seas and Polar Regions. These feed on a variety of food. Some are phytophagous, some are stored grain pest, and some feed on fungi while others on animal matter. Some coleopterans are predators while many are prey for large number of vertebrates including various birds and mammals. Still others are agricultural pest while some are the bio-control agents of the agricultural pest like aphids, whiteflies, *etc*. Hence this order also forms an important component of a habitat, and is included in the present study.

Dipterans the two winged flies is also one of the larger group of class Insecta. This order is important economically. Mosquitoes of this order are vectors of number of human diseases. Their larvae are either aquatic (freshwater), semi-aquatic or live in moist terrestrial habitats. Adults are mostly terrestrial feeding on honey dew, nectar or exudates of various plants and animals while some are predators and others external parasites feeding on blood of human and domestic animals. They form one of the principal component of food for the predacious odonates and hence important in the food web (Mitra, 2007).

Order Lepidoptera, the most attractive group of insects, principally consists of the Butterflies and the Moths. Butterflies, due to their fascinating colours are ideal subjects for ecological study in landscapes (Thomas and Malorie, 1985; Pollard and Yates, 1993) and hence the most studied group. Butterflies are essential part of any natural ecosystem as their adults perform the role as pollinators and the larvae are primary herbivores thereby transferring radiant energy trapped by plants to the next trophic level; rendering dual roles as pollinators and as energy transferors (Sreekumar and Balakrishnan, 2001). Moths included in this order are also pollinators with species like Silk moth being of economic importance. Hence this is very important order from the point of view of energy transfer in the ecosystem.

Order Hymenoptera represented by Bees, Wasp and Ants is also an important food base for aerial as well as ground feeders. According to Brian, (1978) ants are found in any type of habitat from the Arctic Circle to the Equator. They play a major role in most terrestrial ecosystems by performing key ecological functions like nutrient recycling, seed dispersal and acting as the bio-control agents controlling the population of many harmful insects (Holldobler and Wilson, 1990; Folgarait, 1998; Kumar and Mishra, 2008). Wasps are also important natural bio-control agents as many of them are used as the agricultural pest controllers. Bees are main pollinators feeding on nectar and gathering pollen to feed their young while some bees are parasitic in nature too.

Hence in the present study, with terrestrial birds the above mentioned insect orders are also considered for their density and diversity.

The present study was conducted around three reservoirs in the semi arid zone of Central Gujarat. The first is Timbi Irrigation Reservoir (TIR), a reservoir with human activities along with the Narmada inundation. The second reservoir is a reservoir with natural conditions - Jawla Irrigation Reservoir (JIR) as it is the undisturbed reservoir. The third reservoir is a Nationally Important Wetland, Wadhwana irrigation reservoir (WIR) which has received importance since 2005 due to the density and diversity of the waterfowl it supports. This reservoir also receives water from Narmada.

Three irrigation reservoirs selected have different anthropogenic activities around them along with varied hydro-period. The results of the study conducted by Deshkar (2008) and Rathod (2009) suggests that these reservoirs support a large variety of Water birds. In this study, possible influence of the human activities and the prolonged hydro-period on the identified terrestrial fauna (Terrestrial birds and Insects) is considered.

Conservation

In recent years, the sustainable use of the available resources; physical, chemical as well as biological; has become essential for the sustenance of life over a long period of time. Haphazard use of resources is leading to the imbalance in the environment - the most important component for life on earth including men. The alteration in this inevitable resource is leading to the disturbance in the life patterns and deterioration of the system that ultimately leads to the loss of species supported by it. Recently the importance of conservation of the environment has been recognized and hence many organizations have started documenting the status of various species in an ecosystem. Under the Convention on Biodiversity this is expected to help in developing the status and distribution of various species at global level, and also help in conservation of these species and provide them with protective measure to conserve not only the species but the ecosystem or the environment as a whole.

Need of Biodiversity Documentation – An Overview

India is the 6th mega biodiversity nation in the world. Conservation and sustainable use of biodiversity is fundamental to ecologically sustainable development. Biodiversity is part of our daily lives and livelihood, and constitutes resources upon which families, communities, nations and future generations depend. Biological diversity is fundamental to the fulfillment of human needs. An environment rich in biological diversity offers the broadest array of options for sustainable economic activities, for sustaining human welfare and for adapting to change. Loss of biodiversity can have serious economic and social impact on any country. Hence the documentation of the biodiversity in different ecosystems is essential before the species become extinct. Till recently biodiversity surveys largely focused on larger animals, especially vertebrates and even the biodiversity hotspot status has been assigned largely on the basis of data pertaining to vertebrates and flowering plants, while data on invertebrates is insufficient or non-existent (Myers *et al*. 2000; Rangnekar *et al*. 2010).

Though three vertebrate groups *i.e.* mammals, birds and amphibians have been most widely used for comprehensive conservation assessments (Ceballos and Ehrlich, 2006; Stattersfield and Capper, 2000; Stuart *et al*., 2004), the highest extinction risk and therefore greatest loss of biodiversity is expected to be suffered by invertebrates (Thomas *et al*., 2004; Hadfield, 1993), specifically insects (Dunn, 2005). Knowledge of the threat status of invertebrates is limited, and therefore rarely considered for measures of global biodiversity change. The evidence suggests that they might respond in different ways to anthropogenic threats (Thomas *et al*., 2004). Since invertebrates are more specious than vertebrates and in most cases less well known, the task of comprehensively assessing their conservation status is both challenging and time-consuming (Clausnitzer *et al.*, 2009).

Hence, an attempt has been made to document small component of the invertebrate community, the largest invertebrate class, Insecta along with their biggest predator Terrestrial birds around three Irrigation Reservoirs in the semi arid zone of Central Gujarat.

STUDY AREA

In the monsoon dependent semi arid zone of Central Gujarat several irrigation reservoirs were developed in the last century to store rain water. The present study has been conducted around three such irrigation reservoirs (Timbi Irrigation Reservoir, Jawla Irrigation Reservoir and Wadhwana Irrigation Reservoir) in the Vadodara District. All the three reservoirs are situated in different directions of the Vadodara city within 50 Kilometer radius (**Plate 1 and 2**). All the three reservoirs have different land matrix composition and face different types of human pressures.

TIMBI IRRIGATION RESERVOIR (TIR) (Plate 3)

Timbi irrigation reservoir (TIR) is located about 15 kms east of the Vadodara city. This Irrigation reservoir was constructed in the year 1947-48 by the grants provided by His Highness Shrimant Maharaja Sir Sayajirao Gaekwad III of the erstwhile state of Baroda at village Shripor Timbi in the Waghodia Taluka of Vadodara District. It spreads from 22°18' 49" N to 22°18' 53 " N longitude and 73°17' 11" E to 73°17' 22" E latitude. It has an L shaped earthen dam having a periphery of approximately 3 kms and the water cover spreading in an area of 108 acres. It is the smallest reservoir among the three studied in terms of the area. It has become almost perennial wetland due to the inundation from the Sardar Sarovar of Navagam dam on river Narmada. The water from this reservoir is supplied for irrigating eight villages surrounding Shripor Timbi village. It is the reservoir nearest to the city and hence is under the influence of urbanization. The reservoir is surrounded by the urban-rural matrix with scrubland on one side, agricultural fields on the opposite side and one side having the presence of the Educational institutes. Many farmhouses are also developing in the nearby vicinity of the reservoir increasing the anthropogenic activities. Although there is no direct source of pollution to the reservoir, the water of the reservoir is used for the domestic purpose such as washing the clothes and utensils as well as taking bath while the drier side of the reservoir is used for grazing cattle.

The sanitation activity around the wetland has also increased recently. During the last part of the study, *i.e*. in the months of January and February 2011 the surfacing of the road parallel to the earthen dam was initiated that destroyed the flora and ultimately the fauna dependent on the flora .

Climatic Parameters

The climatic parameters for this reservoir are obtained from the Waghodia weather station located 4kms from the reservoir.

Even though WIR and TIR lies only 25 Kms away from each other, good variations are found in the microclimatic conditions at the two reserviors. The mean annual minimum temperature recorded for TIR was 21.1˚C and maximum 33.5˚C (Table A) which is approximately 1˚ higher than the minimum and 1˚lower than the maximum temperature at WIR. However, here the lowest temperature recorded was 11.6˚C in January 2011 and highest 40.8˚C in May 2010. The average minimum and maximum temperatures in summer varied between 22.7˚C to 39˚C, while in monsoon 25.3˚ C to 32.6˚C, post-monsoon 22.3˚C to 32.6˚C and in winter 14˚C to 29˚C respectively. The relative humidity was comparatively high at TIR with average relative humidity of 72% which was highest in monsoon with 83% while lowest in summer with 59%. The average annual Rainfall recorded during study period was 52mm with maximum rainfall in monsoon and light showers in post-monsoon. The annual mean rainfall during the two years of study was 630.25 mm (Table B). Rainfall was mainly noted from June to November in the first year of the study while from June to September in the second year of the study which comes under the monsoon and post-monsoon season considered in the present study. The rainfall noted in the first year (during 6 months) was comparatively low with 35 rainy days compared to the 62 rainy days in (four months) second year of the study.

JAWLA IRRIGATION RESERVOIR (JIR) (Plate 4)

Jawla Irrigation Reservoir (JIR) is located about 30 Kms North of Vadodara city and 1.5 km from the Savli town in Savli Taluka of Vadodara district in the out skirts of Jawla Village. The reservoir is enclosed by an earthen dam, having a periphery of approximately 2 Kms and spreads in an area of 194 acres. It spreads from 22^o 33' 25" N to 22^o 33' 21" N and 73^o 14' 28" E to 73^o 14' 22" E. It has a Hanuman temple on the earthen dam that marks the western boundary of the dam. Though, it is a seasonal reservoir solely depending on the rain water, it did not completely dry off during the study period. The water from this reservoir is supplied for irrigation to the agricultural fields of the surrounding villages. The Jawla village has a different water tank for all the domestic needs and hence the reservoir is not used for the domestic requirements. Cattle grazing was not too frequent at this reservoir. The reservoir is surrounded by agricultural matrix on all the sides, hence faces comparatively less anthropogenic pressures. However, the population from villages that underwent submergence due to Sardar sarovar dam on Narmada River has been shifted near this reservoir. The human habitation coming up near the reservoir has started using surrounding for sanitation and in future may lead to increase in the anthropogenic pressures. Hence proper management is necessary for maintaining the quality of the reservoir.

Climatic Parameters

As there is no weather station in the near vicinity of this reservoir, the temperature and humidity recorded at the Waghodia weather station is taken in to consideration for this reservoir (Table A) too. The annual rainfall at JIR was 639.5 mm during the study period (Table B). Here, in both the years of study, rainfall was noted only for 4 months *i.e.* June to September. As in TIR the rainfall at JIR was also higher during the second year of study with more rainy days *i.e.* 925 mm rainfall in 43 rainy days in comparison to 554 mm rainfall in 28 days of the first year.

WADHWANA IRRIGATION RESERVOIR (WIR) (Plate 5)

Wadhwana Irrigation Reservoir (WIR) is situated about 50 Kms. south- east of Vadodara city in Central Gujarat. This irrigation reservoir was constructed about 100 years ago in the year 1909-1910 by His Highness Shrimant Maharaja Sir Sayajirao Gaekwad III of erstwhile State of Baroda at the Wadhwana village of Dabhoi Taluka of Vadodara District for irrigating the surrounding fields. The dam is mainly semicircular earthen dam of 8.2 Kms. with the periphery of 11.2 Kms and spreads from 22^{o} 10′ 20" N to 22^{o} 10′ 22" N and 73^{o} 29' 2" E to 73^{o} 29' 13" E with an area of 1420 acres under water. Earlier, water of Jojwa dam on Orsang River was brought to this reservoir. However, after construction of Sardar Sarovar dam on Narmada River, Narmada water is also diverted towards this reservoir. The full capacity of the reservoir is 5 billion cubic feet. It irrigates about 8815 hectare land of 25 villages surrounding the dam. Inlet and outlet canals are present with several sub canals distributing water throughout the agricultural area in the region. Because of Narmada inundation around the turn of the Century, it has become a perennial water reservoir. Cattle grazing is moderate but as the reservoir is large it is non-significant for the quality of reservoir. The Reservoir is surrounded by the agricultural fields and the scrubland and hence no major source of pollution is observed at the reservoir. A local community organization name “PRAJIV” (Prakruti Jiv Sansthan, Wadhwana) is active in voluntarily conserving this wetland and hence it has been maintained in good condition since the development of the organization. Anthropogenic pressures have been mainly in the form of bird watchers especially during winter when huge numbers of migratory birds visit the reservoir. On the basis of the waterfowls assemblages supported by this wetland, it was declared as a Wetland of National Importance in 2005 (Deshkar 2008). Forest Department, Government of Gujarat is also actively involved in management of the reservoir.

Climatic Parameters

The temperature at Wadhwana Irrigation reservoir varied between minimum of 6.2˚C in January 2011 to maximum 42.3˚C in May 2010 (Table A). The average minimum temperature recorded during the study period was 20.13˚C while the average maximum temperature was 34.5˚C. However, a lot of differences were noted in the temperature during different seasons of the year. In summer the average temperature varied between minimum 22˚C to maximum 39.7˚C, in monsoon it ranged between 25˚C to 34˚C, in post-monsoon it varied from 21.6˚C to 33.5˚C while in winter it dropped and was noted between minimum 11˚C and maximum of 30˚C. The average relative humidity recorded was 62% while it was maximum 75% in monsoon and minimum 45% in summer. The mean annual average rainfall was nearly 77mm (Table B). The annual rainfall at WIR during the study period was 923 mm. 508mm rainfall was noted in 5 months *i.e* . June to October during the first year with 39 rainy days while in the second year 1338 mm rainfall was noted with 57 rainy days over 6 months *i.e.* June to November.

TIR as well as WIR are given on lease for fishing during summer (March to May) by the government and hence seeds are added to the reservoirs every year and harvested in summer. The fishes harvested include Rohu (*Labio rohita*), Catla (*Catla catla*), Mrigal (*Cirrhinus mrigala*). At TIR, the fishing activities were also observed during other season of the year. As all the three reservoirs are situated in different parts of the district the regional environment is different. The changes in the inundation as well as anthropogenic pressures alter the diversity of the area which is assessed in the present study.

Table A: Minimum Temperature, Maximum Temperature and Relative Humidity noted at the Bhilapur Weather station of the Dabhoi Taluka of Vadodara District (Considered for Wadhwana Irrigation Reservoir) and Waghodia Weather Station of the Vadodara District (Considered for Timbi Irrigation Reservoir and Jawla Irrigation Reservoir)

Months	Minimum Temperature ºC		Maximum Temperature ºC		Relative Humidity %	
	WIR	TIR/JIR	WIR	TIR/JIR	WIR	TIR/JIR
2009						
March	18.0		37.2		41.1	
April	21.0		40		36.3	
May	26.7		39.3		55.9	
June	27.7		37.7		59.1	
July	25.2		32.1		83.8	
August	25.7	24.3	32.7	27.6	77.9	93
September	25.9	25.5	34.5	33.8	73.4	78.4
October	22.9	21.9	34.3	34.3	66.2	68.4
November	16.9	18	31.0	30.4	64.5	70.1
December	14.8	16.2	30.5	29.6	65.4	74.5
2010						
January	13.1	14.4	29.6	29	56.8	68.8
February	14.9		32.3	30.8	54.3	62
March	18.9		38.3	36.2	45.7	60.4
April	22.4		40.8	39.7	43.4	60
May	25.4		42.3	40.8	45.9	60.3
June	24.9		37.8	36.1	65.7	71.7
July	23.7		32.6	31.2	83	87.3
August	24.0		32	30.8	85.1	89
September	23.7	25.2	32.4	31.4	82.1	85.9
October	21.7	23.7	35.6	34.6	64	73.6
November	18.5	20.4	32.9	31.1	70	80.9
December	10.9	13.2	29.7	28.5	63.7	75.3
2011						
January	6.2	11.6	30	28.8	50.5	68.3
February	10	13.9	32.5	31.6	53.1	68.2
March	12.9	16.6	37	36.1	41	72.5

Source: R.G. Subdivision, Kuber Bhavan Vadodara.

Table B: Rainfall and Rainy Days at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Timbi Irrigation Reservoir		Jawla Irrigation Reservoir		Wadhwana Irrigation Reservoir	
	Rainfall	Rainy days	Rainfall	Rainy days	Rainfall	Rainy days
2009						
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	24	1	0	0	22	3
July	177	20	188	19	299	23
August	67.5	7	123	6	131	9
September	28	3	9	1	41	4
October	9	2	34	2	15	2
November	22.5	2	0	0	0	0
December	0	0	0	0	0	0
2010						
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	78	4	33	2	90	4
July	199	22	155	13	380	17
August	377.5	21	468	17	560	18
September	278	15	269	11	253	14
October	0	0	0	0	22	2
November	0	0	0	0	33	2
December	0	0	0	0	0	0
2011						
January	0	0	0	0	0	0
February	0	0	0	0	0	0

Source: R.G. Subdivision, Kuber Bhavan Vadodara

PLATE 1: LOCATION OF THE THREE RESERVOIRS WITH REFERENCE TO VADODARA CITY

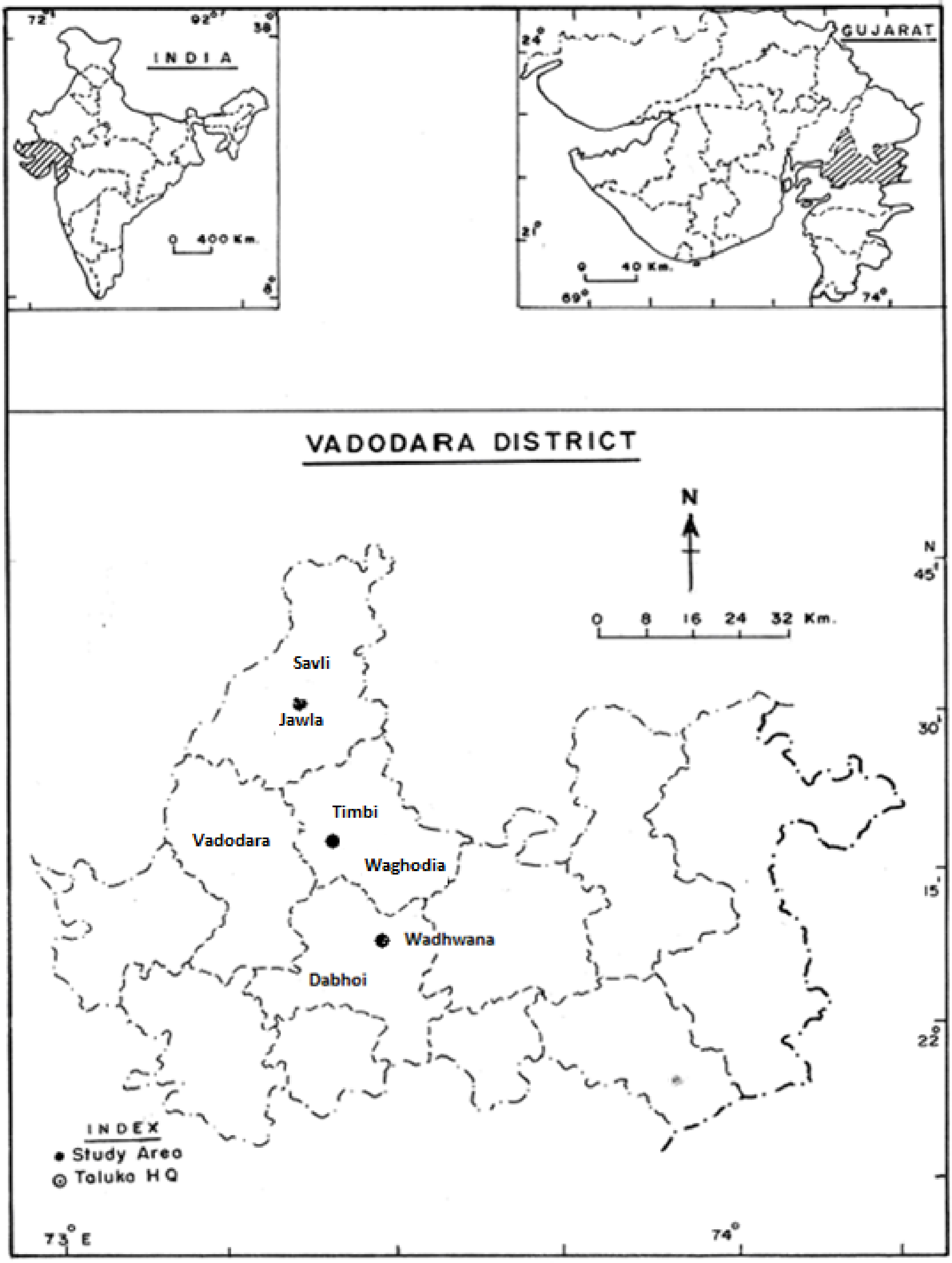


PLATE 2: GOOGLE EARTH IMAGE OF THE THREE RESERVOIRS WITH REFERENCE TO VADODARA CITY

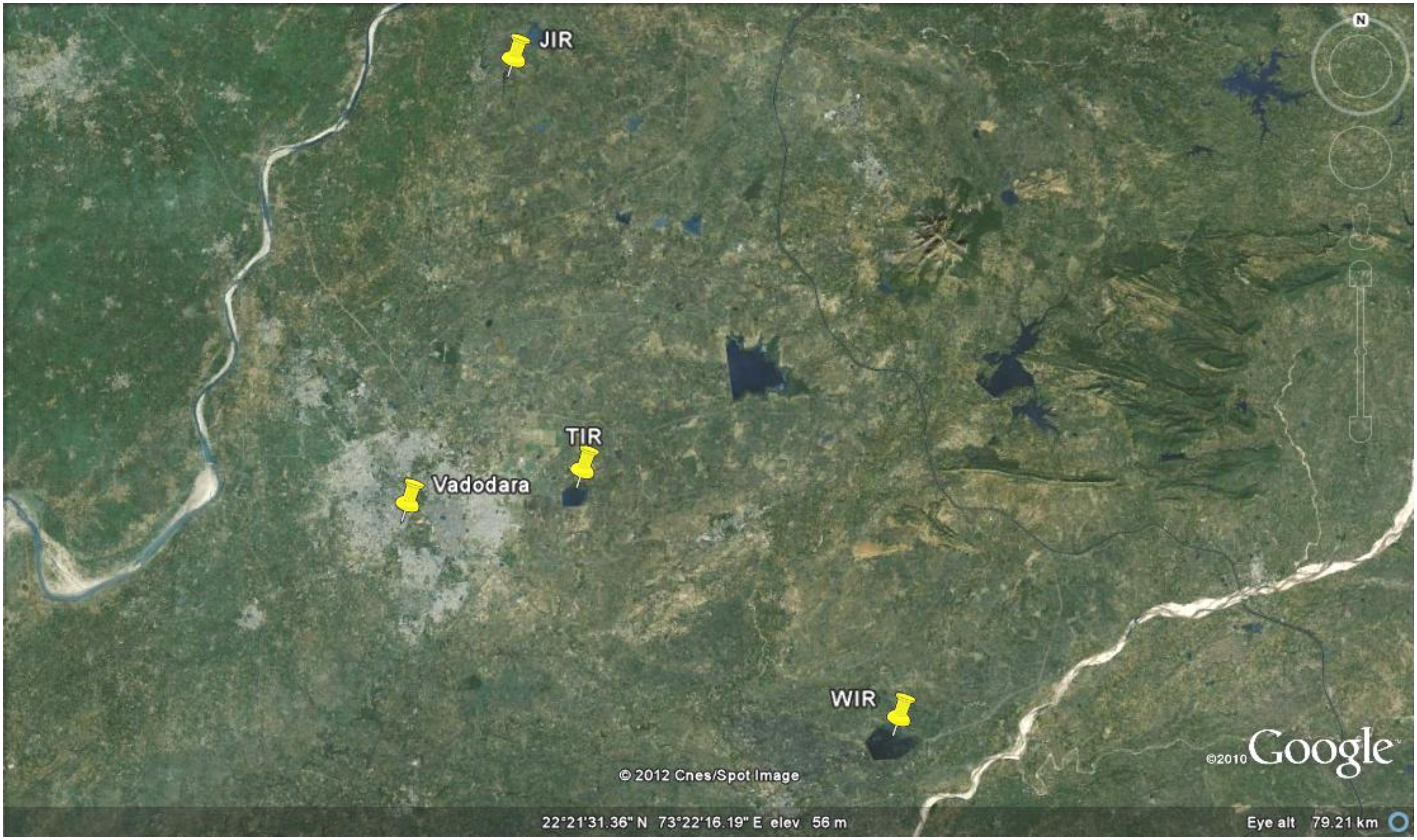


PLATE 3: GOOGLE EARTH IMAGE AND PANORAMIC VIEW OF TIMBI IRRIGATION RESERVOIR (TIR)

PLATE 3 (CONT.): SCRUBLAND AROUND TIR IN POST-MONSOON

DOMESTIC WASTE AT TIR

A. SOLID WASTE **B. DETERGENT INPUT**

PLATE 4: GOOGLE EARTH IMAGE AND PANORAMIC VIEW OF JAWLA IRRIGATION RESERVOIR (JIR)

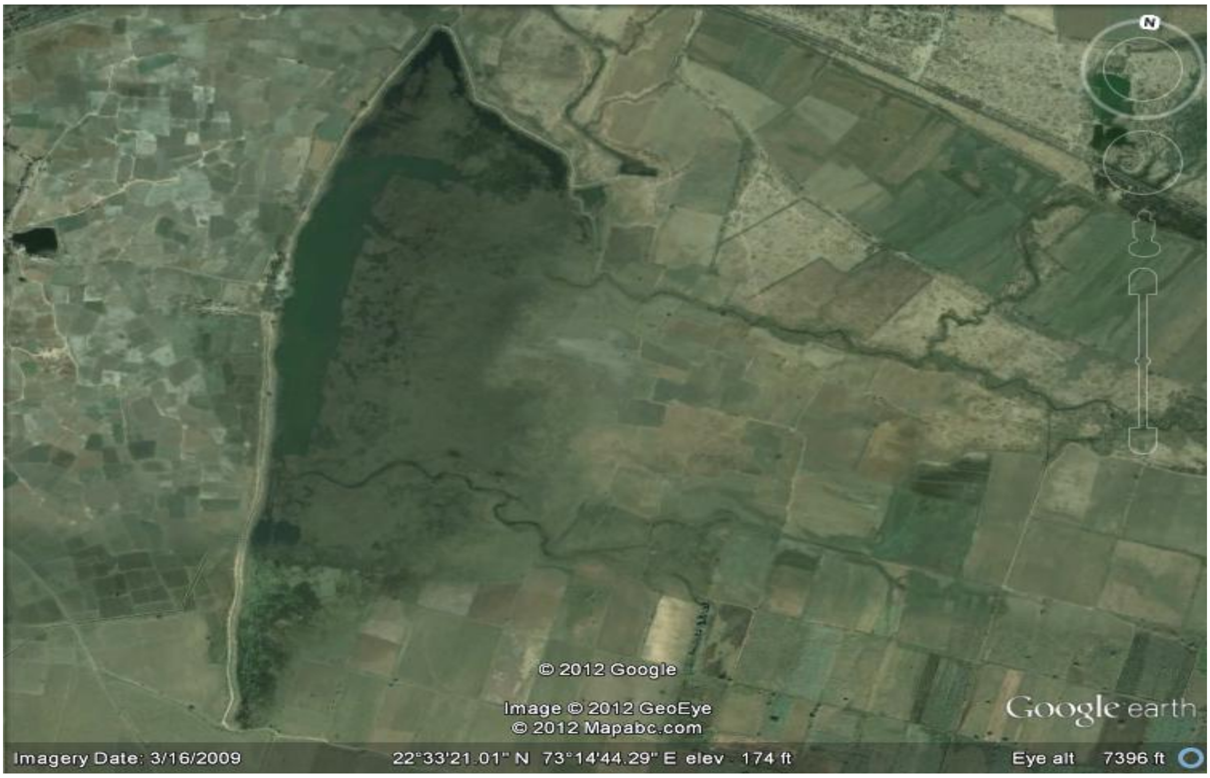


PLATE 4 (CONT.): AGRICULTURAL MATRIX AROUND JIR

VEGETATION ON EARTHEN DAM OF JIR IN POST-MONSOON

PLATE 5: GOOGLE EARTH IMAGE AND PANORAMIC VIEW OF WADHWANA IRRIGATION RESERVOIR (WIR)

WIR IN SUMMER AFTER NARMADA INUNDATION

PLATE 5 (CONT.): WIR IN POST-MONSOON

EARTHEN DAM AND AGRICULTURAL MATRIX AROUND WIR

MATERIALS AND METHODS

The three irrigation reservoirs, Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR) were visited twice in a month from March 2009 to February 2011 and data was collected during morning hours. All together 127 visits were made at the three reservoirs over a period of two years. This includes 45 visits at TIR and WIR each while 37 at JIR.

The methods used to collect data for different taxa are as follows:

Birds – For Calculation of diversity, density and other indices of birds, the census of birds was conducted by walking a fixed transect on the earthen dam during morning hours, half an hour after sunrise, which is known to be the best time for the observation of birds. The terrestrial birds present on both the sides of transect were counted directly with the help of binoculars having the magnification of 10 X 50. As the reservoirs are of different sizes, and the length of the earthen dam also varied, so did the transect length. At Timbi Irrigation Reservoir (TIR) the transect length considered was 1.33 Km, at Jawla Irrigation Reservoir (JIR) 0.89 Km while at Wadhwana Irrigation Reservoir (WIR) it was 3.2 Km (about 25% of the total earthen dam). The total transect width considered was 0.1 Km. The terrestrial birds observed were identified on the basis of field guides by Ali and Ripley, (1983); Grimmett *et al.*, (2001) and Kazmierczak, (2006).

Many species of terrestrial birds are specific for the food they consume while many others feed on wide range of food items with overlapping feeding guilds. The species which feed on more than one type of food were considered in separate specific groups. Hence in the present study to study the feeding guilds of the birds present in the area total eleven groups are considered. These groups are Graminivores, Omnivores, Frugivores, Nectarivores, Insectivores, Carnivores, Bird of Prey, Insectivores + Frugivores, Insectivores + Graminivores, Insectivores + Carnivores and Frugivores + Omnivores.

Insects- The study of insect diversity was conducted between 8:00a.m to 10 a.m. $\pm$1 hour during each visit. The insects present on both the sides of the earthen dam were observed while walking on the feet and recorded. The same transect that was used for birds was used for insects too. The insects that could be identified in the field were identified in the field itself while those that could not be identified on the spot were collected or photographed and identified later on the basis of standard books. For the classification up to family level standard books by Richard and Davies (1984); Norman *et al.,* (1992) and Leffroy (1905) were used. For detailed identification of odonates, guides by Fraser (1933-36), Subramaniam (2005) and Tyagi (2007) were used, Hemipterans were identified from the checklist of the species present in the collection of the Zoology Department, The M.S. University of Baroda; for the butterflies the standard guides by Gay *et al.*, (1992), Haribal (1994), Kunte (2000), Parasharya and Jani (2007) and Kehmikar (2008) are used while the Ants present were identified from the checklist published by http://ces.iisc.ernet.in/thresi/AntsOfIndia.html, Bharti (2008) and Kumar and Mishra (2008). From the different orders of insects present, for four orders with maximum representation species richness, density, diversity indices, percentage occurrence and abundance are considered in detail in separate chapters while rest of the orders are considered with Total insect diversity in Chapter 2.

Abundance rating - All the birds as well as insects observed during the study were given abundance rating according to the rate of their encounter over the study period. The species observed during >30 visits were rated as Abundant, that observed between 21-30 visits as Common, between 11-20 times as Frequent, for 5-10 times as Uncommon and those that were observed <5 times as Rare.

Similarity Index – Similarity index is defined as the statistic to compare the similarity between the two sample sets. The Jaccard's similarity index (J) was calculated to note the degree of similarity between the two habitats (reservoirs). It was calculated as per the formula given by Javed and Kaul (2002)

$$\text{Jaccard's similarity index } J = \frac{c}{(a+b)-c}$$

Where a is number of species at site 1
b is number of species at site 2
c is number of species common at both the sites

Jaccard's similarity index was calculated for Total birds, Total insects and the four major insect groups annually as well as seasonally.

Parameters considered

The Density (Rodgers, 1991) and the Diversity indices like Species Richness, Species diversity - Shannon-Wiener index (H′) and Equitability (E) (Krebs, 1985) are calculated for total birds, Odonata, Hemiptera, Lepidoptera and Hymenoptera for each visit. Only the density and species richness are calculated for the Total insects.

Species Richness –Species Richness is simply considered as the number of different species represented in a set or collection of individuals. Total number of species observed per visit is considered as Species richness for the particular visit. Later the number of species observed during each visit is pooled and finally the mean species richness for annual as well as different seasons is obtained. Species richness was calculated for terrestrial birds, total insects as well as for the four major orders Odonata, Hemiptera, Lepidoptera (Butterflies) and Hymenoptera separately. Many a times this is referred to as α - diversity.

Density –Ecological density or Population density is defined as the number of individuals per unit of suitable habitat area. Density was calculated differently for the different groups. The density for birds is calculated per km^2 with the help of transect method (Rodgers, 1991). The density of the 11 bird groups according to their feeding habits was also calculated. The Formula used for calculating density of birds is as follows:

$$\text{Density} = N/ L * B$$

Where N = Total number of birds
L = Length of the Transect
B = Breadth of Transect

For insects, density was calculated using three methods as per the niche occupied by the group. For the aerial insects density was calculated by the point count method and expressed as no. of insects/ $10m^2$/min. For the insects found on the ground, Quadrat method was employed and the density was expressed as no. of insects/m^2. For the arboreal insects the density was calculated by Bush count method per m^2 (Krebs, 1985; Javed and Kaul, 2002).

Point Count

$$\text{Density} = N/\Pi r^2$$

Where N= Total number of insects
Π =3.14
r = radius of the circle

Quadrat Count

$$\text{Density} = N/l^2$$

Where N = Total number of insects
l = Length of a side

Bush count Method

$$\text{Density} = N/ 2\Pi r^2+2\Pi rh$$

Where N = Total number of insects
Π =3.14
r = fixed radius of the bush
h = fixed height of the bush

Certain groups of insects were observed in more than one niches *i.e.* Odonates mainly damselflies were observed perching on bushes and hence considered in the bush count and expressed per m^2 while the dragonflies were mostly seen in flight and hence estimated by point count and expressed per $10m^2$/min. To avoid confusion the density of all insects groups expressed per m^2 is converted to $10m^2$. For the Hemiptera generally bush count method and Quadrat count was employed and density is expressed per m^2. For Lepidoptera only the butterflies are considered as the study was diurnal and their density is calculated by point count method and the results are expressed per $10m^2$ /min. In case of the Hymenoptera, three distinct groups are found in all the three niches and hence for ground ants Quadrat sampling was done, for ant and wasps on bushes, bush count was employed and for the bees point count was performed and the results are finally expressed per m^2.

Species Diversity Index - Species diversity is an expression of community structure and is a characteristic unique to the community level of organization. Many different indices are present to measure the species diversity. One such index is the Shannon- Wiener Diversity Index (H'). It is calculated as $H' = -\sum pi \ln pi$ (for maximum number of species) where pi is total sample belonging to the i^{th} proportion of a species, calculated as proportion of the total number of individuals of all the species and ln is the natural log.

Evenness (E) – Evenness is defined as how close in numbers are the different species present in the environment. Evenness/equitability is calculated as $E = H' / H\ max$ where H is information content of sample (bits/individuals) = index of species diversity (Krebs, 1985; Javed and Kaul, 2002).

For statistical analysis, the data for 3 months is pooled according to the seasons as Summer: March, April, May; Monsoon: June, July, August; Post-monsoon: September, October, November and Winter: December, January, February. The values are presented as Mean ± Standard Error.

The annual variation among the three reservoirs, the seasonal variations at each and the variations among the three in different seasons are statistically analyzed with ANOVA using Prism 3 software. The p value for ANOVA are insignificant if $P > 0.05$, significant if $P < 0.05$ (*), moderately significant if $P < 0.01$ (**), highly significant if $P < 0.001$

(***) as described by Fowler and Cohen (1995). The Pearson correlation was performed using SPSS 7.0.

Percentage Occurrence - The Annual as well as seasonal Percentage occurrence was calculated only for insects. For Insect chapter it is calculated for each of the nine orders while for the four major orders (Odonata, Hemiptera, Lepidoptera and Hymenoptera) it is calculated for the families represented.

$$\% \text{ Occurrence of Orders} = \frac{\text{Number of times all species belonging to a particular Order observed}}{\text{Total number of all species observed belonging to Class Insecta}}$$

$$\% \text{ Occurrence of families} = \frac{\text{Number of times all species belonging to a particular family observed}}{\text{Total number of all species observed belonging to that order}}$$

TERRESTRIAL BIRD DIVERSITY AROUND WETLANDS

Introduction

In the study of an ecosystem, Aves form one of the major components. Due to their role at different levels in the food web, they are involved in maintaining the equilibrium of various ecosystems. Aves are the only group of vertebrates well adapted to flight and hence can fly away in response to even minimum change in the habitat (Hilden, 1965; Morrison, 1986; Fuller *et al*., 1995; Louette *et al*., 1995) affecting their population (Savard *et al.,* 1998; Jain *et al.,* 2005). This highly mobile and the most charismatic group of Vertebrates has received highest attention as well as protection. They are known to colonize wide variety of habitats (Blair, 1999) and are important biological indicators (Bibby *et al.* 1992, Urfi *et al*., 2005) that determine the health of an ecosystem (Koskimies, 1989; Newton, 1995; O’ Connell *et al.,* 2000; Desai and Shanbhag, 2007; Li and Mundkar, 2007). In the aquatic ecosystem, water birds are considered as indicators of quality of water (Aynalem and Bekele, 2008). As birds occupy high trophic level in the trophic cascade their absence can cause functional disturbance at lower levels (Cody, 1981; Sample *et al.*, 1993; Petterson *et al.*, 1995; Rodewald and James, 1996). Gaston (1975) and Hardy *et al.* (1987) have reported that fluctuations in the bird populations act as the sensitive indicator in the terrestrial as well as aquatic ecosystems. Despite the fact that bird populations may not provide an ideal ‘early warning system’ of environmental deterioration, changes in their density, species diversity and composition, and community structure are believed to provide indication of modification in the habitat in which they live (Temple and Wiens, 1989). Further, estimations of the local densities of the avifauna also help in understanding the abundance of various other organisms on which birds depend (Turner, 2003). Bird population monitoring therefore provides a useful means of evaluating a habitat for conservation efforts and the effects of management interventions (Caughley, 1982; Ntiamoa-Baidu *et al*., 2000).

As the Ramsar Convention was based on Waterfowl assemblages, primarily the water birds are studied at a water body. The water birds or water dependent birds can be easily observed due to their relatively immobile nature, affinity to water and visibility over long distances for longer periods. Nonetheless, the terrestrial birds present around the water body are often overlooked because they are frequently secretive, difficult to locate, and have ephemeral habits (Brown and Collier, 2004). Though, difficult to observe due to their mobile nature, these terrestrial birds are equally important as higher level consumer in the terrestrial habitats and hence ranked as the top predator. The surroundings of aquatic ecosystem form a good habitat for many such terrestrial birds that help in maintaining the food web interactions between the two. As the top order consumer they complete the food chain as well as maintain the ecological equilibrium. As water birds significantly outnumber terrestrial birds (Anderson *et al.,* 2001), when attempts are made to document the birds of a wetland, the terrestrial birds are quite often neglected. The Water birds and the water dependent birds at these three reservoirs have been documented by Deshkar (2008) and Rathod (2009). These are mainly monsoon dependent inland fresh water irrigation reservoirs that have developed over the years into wetlands rich in nutrients that support variety of flora and fauna. Being monsoon dependent they face fluctuations in the water level as well as water cover. As the water birds have already been documented, the present study was planned to evaluate status of terrestrial birds around these reservoirs. The seasonal differences in the density, diversity and the diversity indices of terrestrial birds around each reservoir and the differences among them if any are considered in detail.

Birds choose habitats to which they are well adapted in terms of resource exploitation (Hilden, 1965; Partridge, 1978). The habitat preference by birds mainly depends on difference in food availability, the degree of shelter provided as well as climatic conditions (Alatalo, 1981). The terrestrial birds are adapted to a variety of feeding guilds which determine their density and diversity. The terrestrial bird species feed on different types of food available around the wetlands and hence classified as Insectivores which solely feed on insects, Graminivores on grains, Nectarivores on nectar, Frugivores on fruits and Carnivores that feed on other animals. A group of birds called Birds of Prey hunt for food primarily on the wing, using their keen senses, especially vision. Further, the birds that feed on both animal and plant matter are the Omnivores while there are many species that follow different feeding guilds in young and adult life *i.e.* feed their chicks with insects which are rich in protein content (Immelmann, 1971) and they themselves feed on varied diet. Hence, to find out feeding guilds available for these terrestrial birds in the vicinity of wetland, the terrestrial birds observed were categorized in these guilds (Materials and Methods) and their status is evaluated.

Results

The habitats around the three reservoirs are scrub lands surrounded by agricultural fields where a good diversity of terrestrial birds was observed.

Number of species in various Feeding Guilds. (Table 1.1, Fig. 1.1)

Total 66 species of terrestrial birds belonging to 26 families (Annexure 1) were observed around the three irrigation reservoirs. At WIR and TIR, 58 species each belonging to 23 families were observed, while at JIR 52 species belonging to 26 families were noted. 23 families were common around all the three reservoirs. One species each of the families Picidae, Oriolidae and Stringidae were found only at JIR.

When the feeding guilds are considered, of the total 66 species observed, 24 species belonging to 11 families are pure insectivores, while 10 species feed on other food along with insects. Hence total 34 species belonging to 17 families depended on the insect diversity present around the reservoirs. When reservoirs are considered separately, 22 species each around WIR and TIR and 17 species around JIR were pure insectivores while 9 species around all the three reservoirs fed on other food items including Fruits, Grains and other animals in addition to insects. Further, all together 10 species are pure graminivores (3 families) while 4 species (3 families) feed on insects along with grains (I +G). Of the 10 graminivore species, 9 species were observed at TIR and JIR each while 7 species at WIR. 4 species feeding on insects in addition to grains were common around all three reservoirs. Only 2 Nectarivores (1 family) were observed at JIR and WIR and one at TIR, while a single Frugivore Rose ringed Parakeet (*Psittacula krameri*) was observed at all the three reservoirs. 5 species recorded during the study belonging to 4 families eat insects in addition to fruits. From these, 4 species each were recorded at the three reservoirs. 9 species belonging to 4 families of pure Omnivores were all observed around WIR while 8 were observed around TIR and only 5 around JIR. In addition, 4 species belonging to 3 families are pure Carnivores, of which 3 species each were present at the three reservoirs. One species Indian Roller (*Coracias bengalensis*) that fed on insects in addition to animal prey was common at all three reservoirs. 5 species of birds of prey all belonging to the same family Accipitridae were present only at JIR as Shikra (*Accipiter gentilis)* was absent around other two reservoirs.

Abundance rating

Of all the terrestrial species rated according to the number of times they were observed during the study period (Table 1.2, Fig. 1.2, Annexure 1), at TIR, 6 species (10.34%) comprising Blue Rock Pigeon (*Columba livia*), Laughing Dove (*Streptopelia senegalensis*), Rose ringed Parakeet, Black Drongo (*Dicrurus macrocercus*), House Crow (*Corvus splendens*) and Indian Robin (*Saxicoloides fulicata*) were Abundant. 5 species namely Wire tailed Swallow (*Hirundo smithii*), Common Myna (*Acridotheres tristis*), Paddyfield Pipit (*Anthus rufulus*), Indian Peacock (*Pavo cristatus*) and Grey Francolin (*Francolinus pondicerianus*) comprising 8.62 % of the total species were common, 11 species (18.97 %) were frequent, 17 species (29.32%) uncommon and 19 species (32.76 %) rare. At JIR, only 3 terrestrial bird species (5.76%) namely Rose ringed Parakeet, Common Myna and House Crow were abundant while 3 species (5.76%), Greater Coucal (*Centropus sinensis*), Black Drongo and Common Chiffchaff (*Phylloscopus collybita*) were common, 5 species (9.61%) were frequent, 11 species (21.15%) uncommon and 30 species comprising 57.7% of the total birds were rare. Rose ringed Parakeet, Greater Coucal, Black Drongo, Common Myna and House Crow are the five abundant species (8.62%) around WIR with 8 (13.79%) common species namely Blue Rock Pigeon, Laughing Dove, Asian Koel (*Eudynamys scolopacea*), Wire tailed swallow, Paddy field Pipit, Common Chiffchaff, Indian Robin and Yellow Wagtail (*Motacilla flava*). Here, 15 species (25.86%) were frequent, 21 (36.21%) uncommon and 9 (15.51%) rare.

Jaccard's Similarity Index (J)

The **annual** Jaccard's Similarity Index (Table 1.3, Fig.1.3) between TIR and WIR was 0.87 while similarity index of JIR with TIR and WIR was same 0.72. The **seasonal** Jaccard's Similarity Index (Table 1.3, Fig 1.4) between the reservoirs was maximum in winter compared to other seasons, with 71% species common between TIR and WIR and 66% species common between both JIR and WIR as well as JIR and TIR. During summer the similarity index between TIR and WIR was maintained at 0.7 while that between TIR and JIR, and JIR and WIR was lowered to 0.56 and 0.55 respectively. The similarity indices between the reservoirs were low during monsoon at 0.52 between TIR and WIR, 0.55 between TIR and JIR and 0.47 between JIR and WIR, while varied during post monsoon at 0.67, 0.46 and 0.55 respectively.

Total Birds

Annual Differences between three reservoirs (Table 1.4, Fig. 1.5**)**

The mean annual **species richness** was highest 15.98 ±0.83 species at WIR followed by 14.89 ± 0.85 species at TIR and lowest 10.87 ± 0.52 species at JIR. The differences among the reservoirs were highly significant ($p < 0.001$, $F_{(2, 124)}$ 11.52). However, the mean annual **density** of total birds was highest 791.31 ± 96.04 birds/km^2 at TIR while lowest 378.5 ± 58.2 birds/km^{2}at WIR. The density at JIR was 565.6 ± 71.4 birds/km^2. The differences in the density were highly significant ($p < 0.001$, $F_{(2, 124)}$ 7.4). The mean annual **Shannon weiner diversity index** (H') differed non significantly ($P > 0.05$, $F_{(2, 124)}$ 0.48) and was 1.94 ± 0.08 at WIR and almost same 1.86 ± 0.08 and 1.84 ± 0.06 for TIR and JIR respectively. The mean annual **Evenness** was almost maintained at the three reservoirs with 0.72 ± 0.03 for TIR, 0.79 ± 0.02 for JIR and 0.73 ± 0.03 for WIR. Evenness also differed non significantly ($P > 0.05$, $F_{(2, 124)}$ 2.12).

Seasonal Variations at the three reservoirs (Table 1.5, Fig. 1.6)

Mean Species Richness

Seasonal Differences around each reservoir

TIR had highest mean species richness 16.91 ± 2.47 species of terrestrial birds during Post monsoon while lowest 13.2 ± 1.22 species in monsoon. In winter and summer the species richness were 14 ±1.7 species and 15.33 ± 1.08 species respectively. The seasonal variations were non- significant ($P > 0.05$, $F_{(3,41)}$ 0.87). The second reservoir JIR, supported maximum 12.45 ± 0.82 species of terrestrial birds in winter which decreased in summer to 10.25 ± 0.94 species and further decreased to lowest 9.25 ± 0.94 species in monsoon while increased to 11.29 ± 1.48 species in post-monsoon ($P > 0.05$, $F_{(3,34)}$ 1.85). The largest reservoir WIR supported maximum species of terrestrial birds 20.5 ± 1.3 species in winter and minimum 12.1 ± 1.05 species in monsoon as well as 12.92 ± 1.36 species in summer. Higher species richness of 18.1 ± 1.43 species was found in post-monsoon. The seasonal variations were highly significant ($p < 0.001$, $F_{(3,40)}$ 9.58).

Differences among the reservoirs in different seasons

The differences in the species richness of terrestrial birds between the reservoirs were non-significant ($P > 0.05$) in monsoon and post-monsoon. In monsoon species richness varied in narrow range among the three reservoirs with $F_{(2,25)}$ 3.19. During Post-monsoon lowest species richness was recorded for JIR while highest for WIR with non significant differences ($P > 0.05$, $F_{(2,25)}$ 2.75). In the next season winter highest species richness was again recorded at WIR while lowest at JIR with highly significant differences ($P < 0.001$, $F_{(2,32)}$ 10). At the end in summer lowest species richness was noted at JIR and the highest at TIR with significant differences among the reservoirs ($p < 0.05$, $F_{(2,33)}$ 4.97).

Mean Density

Seasonal Differences in the mean density of terrestrial birds

At TIR, the mean density of terrestrial birds was highest 1135.34 ± 205.1 birds/km^2 in winter and lowest 424.8 ± 115.5 birds/km^2 in monsoon. During summer and post-monsoon the densities were 738.1 ± 117.6 birds/km^2 and 807.24 ± 250 birds/km^2 respectively ($P > 0.05$, $F_{(3,41)}$ 2.47). At JIR also the highest density of terrestrial birds was observed in winter (922.37 ±186.2 birds/km^2) and lowest 262.64 ± 27.19 birds/km^2 during monsoon with moderate densities of 434.5 ± 64.95 birds/km^2 in summer and 576.2 ± 99.13 birds/km^2 in post-monsoon with significant seasonal variations ($P < 0.01$, $F_{(3,34)}$ 5.14). At the third reservoir WIR, maximum mean density of terrestrial birds was observed in post-monsoon (742.19 ± 176.7 birds/km^2) followed by winter (445.57 ± 92.73 birds/km^2) while in summer it was 174.2 ± 21.28 birds/km^2 and monsoon 179.68 ± 38.04 birds/km^2 ($P < 0.001$, $F_{(3,40)}$7.33).

Differences among the reservoirs in different seasons

When the differences among the three reservoirs are considered, it is seen that in all the seasons the mean density of terrestrial birds was minimum at WIR except in post monsoon when it was minimum at JIR. The differences were non-significant ($P > 0.05$) for monsoon and post monsoon, significant at $P < 0.001$ in summer and at $P < 0.05$ in winter. The f value for summer, monsoon, post-monsoon and winter were $F_{(2,33)}$ 12.92, $F_{(2,25)}$ 2.72, $F_{(2,25)}$ 0.32 and $F_{(2,32)}$ 4.55 respectively.

Mean Shannon Weiner Diversity Index (H')

Seasonal Differences around each reservoir

When the seasonal differences are considered, H' varied non-significantly ($P > 0.05$, $F_{(3,41)}$ 1.78) at TIR with maximum 2.1 ± 0.12 H' in monsoon and minimum 1.62 ± 0.16 in winter. In summer and post monsoon it was 1.8 ± 0.13 and 1.97 ± 0.19 respectively. At JIR also H' varied non-significantly ($P > 0.05$, $F_{(3,34)}$ 0.59) within a narrow range of 1.9 ± 0.12, 1.94 ± 0.14, 1.81 ± 0.17 and 1.73 ± 0.1 for summer, monsoon, post-monsoon and winter respectively. However, at WIR mean H' varied significantly ($P < 0.05$) with highest 2.24 ± 0.14 in winter and lowest 1.58 ± 0.18 in post monsoon while it was nearly same 1.94 ± 0.13 in summer and 1.95 ± 0.15 in monsoon ($F_{(3,40)}$ 3.27).

Differences among the reservoirs in different seasons

The comparison of H' in different seasons among the reservoirs indicates that during summer there was no major difference in mean H' amongst the three reservoirs ($P > 0.05$, $F_{(2,33)}$ 0.34). However, during monsoon H' was non-significantly higher at TIR compared to almost same values for WIR and JIR ($F_{(2,25)}$ 0.46). In post-monsoon also non-significant ($P > 0.05$, $F_{(2,25)}$ 1.28) differences were noted in the diversity index with higher diversity at TIR and JIR while lower at WIR, while during winter maximum mean H' was recorded for WIR while at TIR and JIR H' was nearly same. The differences among the reservoirs in winter were significant at $P < 0.01$, ($F_{(2,32)}$ 5.75).

Mean Evenness (E)

Seasonal Differences around each reservoir

When seasonal Differences at a single reservoir are considered it was found that at TIR, mean evenness varied non-significantly ($P > 0.05$) ranging from maximum 0.83 ± 0.04 in monsoon to minimum 0.65 ± 0.06 in winter. During summer and post monsoon it was 0.67 ± 0.05 and 0.74 ± 0.04 respectively ($F_{(3, 41)}$ 2.64). However, at JIR evenness showed variations at $P < 0.01$ with maximum 0.88 ± 0.03 in monsoon and minimum 0.69 ± 0.04

in winter. During summer and post monsoon mean E was 0.83 ± 0.03 and 0.76 ± 0.04 respectively ($F_{(3,34)}$ 5.45). Further, at WIR, evenness was low only in post monsoon (0.56 ± 0.07) while over rest of the year it was almost maintained at 0.78 ± 0.04, 0.8 ± 0.04 and 0.75 ±0.04 in summer, monsoon and winter respectively with $P < 0.01$, $F_{(3,40)}$ 4.48.

Differences among the reservoirs in different seasons

Among the three reservoirs mean evenness was maximum at JIR in all the seasons except winter while it was lowest during summer and winter at TIR and during monsoon and post monsoon at WIR. The evenness differed significantly ($P < 0.05$) in summer and post monsoon with $F_{(2,33)}$ 3.67, and $F_{(2,25)}$ 3.69 respectively, while non-significantly ($P > 0.05$) in monsoon and winter with $F_{(2,25)}$ 1.1 and $F_{(2,32)}$ 1.19.

Density of Terrestrial Birds belonging to various feeding guilds around three reservoirs

Differences were noted in the density of terrestrial birds belonging to various feeding guilds like Graminivore, Frugivore, Insectivore, Omnivore, Carnivore, Nectarivore, Birds of Prey, Insectivore + Graminivore, Insectivore + Frugivore, Insectivore + Carnivore, Frugivore + Omnivore.

Annual Density (Table 1.6)

At TIR the mean annual density of Graminivores was maximum 223.2 ± 52.07 birds/km^2 followed by insectivores 177.3 ± 49.5 birds/km^2, Insectivores + Graminivores 120.8 ± 42.9 birds/km^2, Omnivores 83.71 ± 8.12 birds/km^2, Insectivores + Frugivores 73.35 ± 32.21 birds/km^2 and Frugivores 73.02 ± 8.45 birds/km^2. The groups in minority were Birds of Prey with 5.18 ±1.75 birds/km^2, Carnivores 4.18 ± 1 birds/km^2, Frugivores + Omnivores with 2.67 ± 0.54 birds/km^2, Nectarivores with 1.84 ± 1.1 birds/km^2 and Insectivores + Carnivores with only 0.5 ± 0.28 bird/km^2 .

However at JIR, mean density of Frugivores was maximum with 151.4 ± 19.78 birds/km^2 followed by Graminivores 116.2 ± 50.64 birds/km^2, Omnivores 105.6 ±7.85

birds/km^2, Insectivores 98.17 ± 19.34 birds/km^2, Insectivores + Graminivores 36.96 ± 24 birds/km^2, Insectivores +Frugivores 26.02 ± 12.03 birds/km^2, Carnivores 12.42 ±1.98 birds/km^2 and Nectarivores 10.35 ± 2.52 birds/km^2. Other groups had very low density of 3.84 ± 1.29 birds/km^2 for Birds of Prey, 2.36 ± 1.13 birds/km^2 for Frugivores + Omnivores and 0.59 ± 0.41 bird/km^2 for Insectivores + Carnivores.

Different community structure was noted at WIR with highest density of 134.9 ± 39.74 birds/km^2 for Insectivores followed by moderate density of 87.5 ± 31.96 birds/km^2 of Graminivores, 52.91 ± 17.18 birds/km^2 of Insectivores + Graminivores, 45.53 ± 3.85 birds/km^2 of Frugivores and 40.41 ± 3.85 birds/km^2 of Omnivores. The other groups with low density include Insectivores + Frugivores with 5.68 ± 1.05 birds/km^2, Carnivores with 5.11 ± 0.42 birds/km^2, Birds of Prey 2.98 ± 0.55 birds/km^2, Frugivores + Omnivores with 2.2 ± 0.37 birds/km^2, Nectarivores with 1.07 ± 0.37 birds/km^2 and lowest Insectivores+ Carnivores with 0.14 ± 0.1 bird/km^2.

The differences in the mean density amongst the three reservoirs were non-significant for Graminivores, Insectivores, Birds of Prey, Insectivores + Frugivores, Insectivores+ Graminivores, Insectivores + Carnivores and Frugivores + Omnivores whereas highly significant at 0.001 for Omnivores ($F_{(2,124)}$ 23.17), Frugivores ($F_{(2,124)}$19.75), Nectarivores ($F_{(2,124)}$11.35) and Carnivores ($F_{(2,124)}$12.94).

Seasonal Differences in Mean Density of birds in various feeding guilds (Table 1.7)

a) *Within the groups*

When the seasonal differences are considered it was found that Graminivores dominated at both TIR and JIR in winter while at WIR during post- monsoon. The Graminivore density was lowest in post-monsoon at TIR, in monsoon at JIR and in summer at WIR. At all the three reservoirs the seasonal variations were non-significant ($P > 0.05$). Population of Omnivores was highest during post- monsoon at TIR and during winter at JIR and WIR, while lowest during monsoon at JIR and WIR and in winter at TIR. The seasonal variations were highly significant ($P < 0.001$, $F_{(3,40)}$ 14.33) at WIR and non-significant ($P > 0.05$) for TIR and JIR. The density of Frugivores was highest during winter at JIR while during summer at WIR. At JIR and WIR lowest density was observed during monsoon and winter respectively with significant ($P < 0.05$) seasonal variations with $F_{(3,34)}$ 3.17 and $F_{(3,40)}$ 2.87 respectively. At TIR, non-significant seasonal variations were observed in the Frugivore density. The density of Nectarivores was very low all throughout the year around the three reservoirs and hence varied non-significantly ($P > 0.05$). Highest density of Insectivores was noted during post monsoon around all three reservoirs while lowest density was observed in monsoon at TIR and JIR and during summer at WIR. The seasonal variations were significant ($P < 0.05$) for JIR and WIR with $F_{(3,34)}$ 3.94 and $F_{(3,40)}$ 3.24 while non-significant at TIR. Though carnivore density was high at JIR all throughout the year, seasonal variations were non-significant. However, amongst the two other reservoirs with lower density of carnivores the seasonal variations were non-significant at TIR while significant at level of 0.05 at WIR ($F_{(3,40)}$ 3.66). Birds of Prey also had lower density all throughout the year, with non-significant increase noted during post-monsoon at TIR and monsoon at JIR while at WIR the seasonal differences were highly significant ($P < 0.001$, $F_{(3,40)}$ 14.82) with maximum density in winter. Insectivores + Frugivores had highest density in summer and lowest during monsoon at TIR, while at JIR their density was comparatively low all throughout the year except winter when it was high. At WIR density was low all throughout the year. The seasonal variations at the three reservoirs were non-significant. The density of Insectivores + Graminivores varied non-significantly ($P > 0.05$) with highest density during winter and lowest during monsoon at TIR and JIR. At WIR the densities were higher during post monsoon and winter with significant variations ($P < 0.05$, $F_{(3,40)}$ 3.69). Insectivore + Carnivore group was represented by a single species that too encountered rarely hence no trend could be hypothesized for this group. Similarly Frugivore +

Omnivore was also represented by a single species but with low density all throughout the year, and significant seasonal variations at $P < 0.01$ ($F_{(3,41)}$ 5.69) at TIR and highly significant ($P < 0.001$, $F_{(3,40)}$ 8.69) at WIR. This group was not represented during post-monsoon and winter at JIR while during winter at TIR.

b) Amongst the reservoirs in different seasons

When the comparison is made between three reservoirs in different seasons, it was found that Graminivore showed significant ($P < 0.05$, $F_{(2,33)}$ 3.9) differences during summer, while during rest of year the differences among the three reservoirs were non-significant ($P > 0.05$). The differences in the density of Omnivores at the three reservoirs was significant at $P < 0.001$ ($F_{(2,33)}$ 12.28) in summer, at $P < 0.01$ ($F_{(2.25)}$ 9) and $F_{(2.25)}$ 5.64 during monsoon and post-monsoon respectively while non-significant in winter. Though Frugivore was represented by single species the differences in their densities among the three reservoirs were highly significant ($P < 0.01$) during post-monsoon and winter with $F_{(2,25)}$ 9.72 and $F_{(2,32)}$ 16.48 respectively, while non significant during summer and monsoon ($P < 0.05$). Although Nectarivores consisted of two species at WIR and JIR and a single species at TIR the differences among their density around three reservoirs were significant at $P < 0.01$, ($F_{(2.32)}$7.18) in winter and at $P < 0.05$, ($F_{(2,33)}$ 5.27) during summer, whereas non-significant in other two seasons. Insectivores comprising the largest group failed to show any variations among the three reservoirs all throughout the year. Carnivores showed significant differences at level of $P < 0.01$ only during monsoon and winter with $F_{(2.25)}$ 6.79 and $F_{(2,32)}$ 6.17 respectively. The differences for the Birds of Prey and Insectivores + Frugivores were non-significant ($P > 0.05$) all throughout the year while Insectivores + Graminivores showed significant differences at $P < 0.05$ ($F_{(2,33)}$ 4.37) during summer and at $P < 0.01$ ($F_{(2.25)}$ 6.44) during monsoon while differences in post-monsoon and winter were non-significant. As said earlier Insectivore + Carnivore and Frugivore + Omnivore were represented by a single species each that were encountered occasionally, hence no specific trend could be developed for these groups.

Table 1.1: Distribution of terrestrial birds according to their feeding habits at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Total	**Gr**	**Om**	**Fr**	**Ne**	**In**	**Ca**	**BOP**	**I +F**	**I + G**	**I + C**	**F + O**
TOTAL	66	10	9	1	2	24	4	5	5	4	1	1
TIR	58	9	8	1	1	22	3	4	4	4	1	1
JIR	52	9	5	1	2	17	3	5	4	4	1	1
WIR	58	7	9	1	2	22	3	4	4	4	1	1

Gr – Graminivore, Om – Omnivore, Fr- Frugivore, Ne – Nectarivore, In – Insectivore, Ca – Carnivore, BOP - Birds Of Prey, I+F - Insectivore + Frugivore, I+G - Insectivore + Graminivore, I+C - Insectivore + Carnivore, F+O - Frugivore + Omnivore

Table 1.2: Abundance rating of the terrestrial birds encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Abundant	**Common**	**Frequent**	**Uncommon**	**Rare**
TIR	6 (10.34%)	5 (8.62%)	11 (18.97%)	17 (29.32%)	19 (32.76%)
JIR	3 (5.76%)	3 (5.76%)	5 (9.61%)	11 (21.15%)	30 (57.7%)
WIR	5 (8.62%)	8 (13.79%)	15 (25.86%)	21 (36.21%)	9 (15.51%)

Table 1.3: Annual and Seasonal Jaccard's Similarity Index (J) of terrestrial birds between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Annual		**Summer**		**Monsoon**		**Post-monsoon**		**Winter**	
	TIR	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**
WIR	0.87	0.72	0.7	0.55	0.52	0.47	0.67	0.55	0.71	0.66
JIR	0.72	-	0.56	-	0.55	-	0.46	-	0.66	-

Table 1.4: Annual Mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of the Terrestrial Birds at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Species Richness (***) $F_{(2,124)}$ **11.52**	**Density (***)** $F_{(1,124)}$ **7.4**	**Shannon Weiner index (ns)** $F_{(1,124)}$ **0.48**	**Evenness (ns)** $F_{(2,124)}$ **2.12**
TIR	14.89 ± 0.85	791.31 ± 96.04	1.86 ± 0.08	0.72 ± 0.03
JIR	10.87 ± 0.52	565.6 ± 71.4	1.84 ± 0.06	0.79 ± 0.02
WIR	15.98 ± 0.83	378.5 ± 58.2	1.94 ± 0.08	0.73 ± 0.03

Table 1.5: Seasonal variations in the Mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of the Terrestrial Birds at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

			Summer	**Monsoon**	**Post monsoon**	**Winter**
Species Richness		**Among Reservoir** / **Within Reservoir**	(*) $F_{(2.33)}$ **4.97**	(ns) $F_{(2,25)}$ **3.19**	(ns) $F_{(2,25)}$ **2.75**	(***) $F_{(2,32)}$ **10**
	TIR	**(ns)** $F_{(3,41)}$ **0.87**	15.33 ± 1.08	13.2 ± 1.22	16.91 ± 2.47	14 ±1.7
	JIR	**(ns)** $F_{(3,34)}$ **1.85**	10.25 ± 0.94	9.25 ± 0.94	11.29 ± 1.48	12.45 ± 0.82
	WIR	**(***)** $F_{(3,40)}$ **9.58**	12.92 ± 1.36	12.1 ± 1.05	18.1 ± 1.43	20.5 ± 1.3
Density			(***) $F_{(2,33)}$**12.92**	(ns) $F_{(2,25)}$ **2.72**	(ns) $F_{(2,25)}$ **0.32**	(*) $F_{(2,32)}$ **4.55**
	TIR	**(ns)** $F_{(3,41)}$ **2.47**	738.1 ± 117.6	424.8 ± 115.5	807.24 ± 250	1135.34± 205.1
	JIR	**(**)** $F_{(3,34)}$ **5.14**	434.5 ± 64.95	262.64 ± 27.19	576.2 ± 99.13	922.37 ±186.2
	WIR	**(***)** $F_{(3,40)}$ **7.33**	174.2 ± 21.28	179.68 ± 38.04	742.19 ±176.7	445.57 ± 92.73
Shannon Weiner index(H')			(ns) $F_{(2,33)}$**0.34**	(ns) $F_{(2,25)}$ **0.46**	(ns) $F_{(2,25)}$ **1.28**	(**)$F_{(2,32)}$ **5.75**
	TIR	**(ns)** $F_{(3,41)}$ **1.78**	1.8 ± 0.13	2.1 ± 0.12	1.97 ± 0.19	1.62 ± 0.16
	JIR	**(ns)** $F_{(3,34)}$ **0.59**	1.9 ± 0.12	1.94 ± 0.14	1.81 ± 0.17	1.73 ± 0.1
	WIR	**(*)** $F_{(3,40)}$ **3.27**	1.94 ± 0.13	1.95 ± 0.15	1.58 ± 0.18	2.24 ± 0.14
Evenness (E)			(*)$F_{(2,33)}$ **3.67**	(ns) $F_{(2,25)}$ **1.1**	(*)$F_{(2,25)}$ **3.69**	(ns) $F_{(2,32)}$ **1.19**
	TIR	**(ns)** $F_{(3,41)}$ **2.64**	0.67 ± 0.05	0.83 ± 0.04	0.74 ± 0.04	0.65 ± 0.06
	JIR	**(**)** $F_{(3,34)}$ **5.45**	0.83 ± 0.03	0.88 ± 0.03	0.76 ± 0.04	0.69 ± 0.04
	WIR	**(**)** $F_{(3,40)}$ **4.48**	0.78 ± 0.04	0.80 ± 0.04	0.56 ± 0.072	0.75 ± 0.04

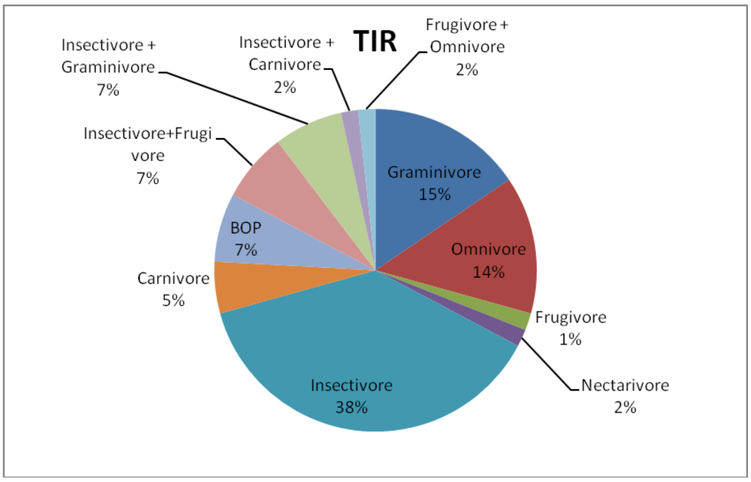
Table 1.6: Annual density of the groups of Birds belonging to various feeding guilds at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

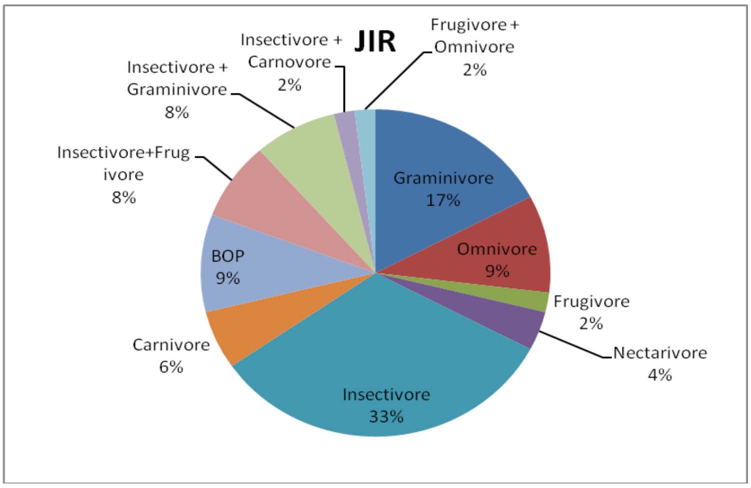
Sr. No.	Groups		TIR	JIR	WIR
1	Graminivore	(ns) $F_{(2,124)}$ **2.57**	223.2 ±52.07	116.2 ± 50.64	87.5 ± 31.96
2	Omnivore	(***)$F_{(2,124)}$ **23.17**	83.71 ± 8.12	105.6 ±7.85	40.41 ± 3.85
3	Frugivore	(***)$F_{(2,124)}$**19.75**	73.02 ± 8.45	151.4 ± 19.78	45.53 ±6.01
4	Nectarivore	(***)$F_{(2,124)}$ **11.35**	1.84 ± 1.1	10.35 ± 2.52	1.07 ± 0.37
5	Insectivore	(ns) $F_{(2,124)}$ **0.96**	177.3± 49.5	98.17 ± 19.34	134.9 ± 39.74
6	Carnivore	(***)$F_{(2,124)}$ **12.94**	4.18 ±1	12.42 ± 1.98	5.11± 0.42
7	Birds Of Prey	(ns) $F_{(2,124)}$ **0.75**	5.18 ±1.75	3.84 ± 1.29	2.98 ± 0.55
8	Insectivore + Frugivore	(ns) $F_{(2,124)}$ **2.94**	73.35±32.21	26.02 ± 12.03	5.68 ± 1.05
9	Insectivore + Graminivore	(ns) $F_{(2,124)}$ **2.1**	120.8±42.9	36.96 ± 24	52.91 ± 17.18
10	Insectivore + Carnivore	(ns) $F_{(2,124)}$ **0.71**	0.50 ± 0.28	0.59 ± 0.41	0.14 ± 0.1
11	Frugivore + Omnivore	(ns) $F_{(2,124)}$ **0.12**	2.67 ± 0.54	2.36 ± 1.13	2.20 ± 0.37

Table 1.7: Seasonal variations in the density of the groups of Birds belonging to various feeding guilds at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

			Summer	Monsoon	Post monsoon	Winter
Graminivore		Among Reservoir / Within Reservoir	(*) $F_{(2,33)}$ 3.9	(ns) $F_{(2,25)}$ 1.57	(ns) $F_{(2,25)}$0.56	(ns) $F_{(2,32)}$1.54
	TIR	(ns) $F_{(3,41)}$ 1.39	174.8 ± 67.9	166.2 ± 96.27	139.4 ± 63.79	396 ± 150.3
	JIR	(ns) $F_{(3,34)}$ 1.79	52.43 ± 22.44	18.26 ± 7.34	59.39 ± 46.7	293.20 ±163.8
	WIR	(ns) $F_{(3,40)}$ 1.69	19.79 ± 4.78	46.880 ± 30.54	208.10 ± 128.4	88.54 ± 33.28
Omnivore			(***)$F_{(2,33)}$12.28	(**) $F_{(2,25)}$9	(**)$F_{(2,25)}$5.64	(ns) $F_{(2,32)}$2.94
	TIR	(ns) $F_{(3,41)}$ 0.44	89.60 ± 11.69	86.470 ± 16.1	91.590 ± 18.36	68.30 ± 19.07
	JIR	(ns) $F_{(3,34)}$ 0.35	110.5 ± 16.35	89.89 ± 15.31	105.9 ± 19.59	111.3 ± 13.33
	WIR	(***) $F_{(3,40)}$ 14.33	29.95 ± 4.78	23.13 ±3.64	35.63 ± 5.42	69.27 ± 7.1
Frugivore			(ns) $F_{(2,33)}$ 2.45	(ns) $F_{(2,25)}$ 0.94	(***)$F_{(2,25)}$9.72	(***)$F_{(2,32)}$16.48
	TIR	(ns) $F_{(3,41)}$ 0.23	70.8 ± 16.7	69.17 ± 16.12	66.3 ± 18.13	84.590 ± 18
	JIR	(*) $F_{(3,34)}$ 3.17	144.20 ± 41.37	67.42 ±15.46	141.30 ± 20.35	226.8±39.71
	WIR	(*) $F_{(3,40)}$ 2.87	71.09 ±14.2	45.31 ±10.1	33.130 ± 10.3	30.47 ± 8.97
Nectarivore			(*)$F_{(2,33)}$5.27	(ns) $F_{(2,25)}$ 0.6	(ns) $F_{(2,25)}$1.65	(**)$F_{(2,32)}$ 7.18
	TIR	(ns) $F_{(3,34)}$0.56	1.253 ± 1.253	4.51 ± 4.51	0.68 ± 0.68	1.25 ± 1.25
	JIR	(ns)$F_{(3,34)}$ 1.95	13.11 ± 4.76	1.40 ± 1.4	6.42 ± 4.82	16.34 ± 5.74
	WIR	(ns)$F_{(3,40)}$ 0.7	1.82 ± 1.12	0.31 ± 0.31	0.94 ± 0.48	1.04 ± 0.59
Insectivore			(ns) $F_{(2,33)}$1.9	(ns) $F_{(2,25)}$0.62	(ns) $F_{(2,25)}$ 0.26	(ns) $F_{(2,32)}$1.39
	TIR	(ns) $F_{(3,41)}$ 2.5	73.93 ±13.91	62.41± 18.92	388.90 ±185.6	182.30±43.48
	JIR	(*) $F_{(3,34)}$ 3.94	72.10 ± 17.84	37.9 ± 5.98	216.70±88.05	94.990±13.75
	WIR	(*) $F_{(3,40)}$ 3.24	37.50 ± 12.44	49.69 ±14.75	334.40±153.9	137.2 ±42
Carnivore			(ns) $F_{(2,33)}$2.34	(**) $F_{(2,25)}$ 6.79	(ns) $F_{(2,25)}$0.91	(**)$F_{(2,32)}$6.17
	TIR	ns) $F_{(3,41)}$ 1.57	5.64 ± 2.64	2.26 ± 1.6	6.84± 1.88	1.88± 1.35
	JIR	(ns)$F_{(3,34)}$ 0.23	13.11 ± 4.34	11.24 ± 3.	9.63 ± 2.93	14.3± 4.31
	WIR	(*) $F_{(3,40)}$ 3.66	4.69 ± 0.98	3.13 ± 0.66	5.94 ± 0.73	6.51 ± 0.60
Birds Of Prey			(ns) $F_{(2,33)}$0.52	(ns) $F_{(2,25)}$ 2.57	(ns) $F_{(2,25)}$1.93	(ns) $F_{(2,32)}$1.02
	TIR	(ns) $F_{(3,41)}$ 1.22	3.76 ± 2.7	2.26 ± 2.26	10.94 ± 5.94	3.76 ± 1.46
	JIR	(ns) $F_{(3,34)}$ 1.9	1.87± 1.87	8.43 ± 4.11	0	5.11 ± 2.33
	WIR	(***) $F_{(3,40)}$ 14.82	1.04 ± 0.59	0.63 ±0.42	2.81 ± 0.87	7.03 ± 1.03
Insectivore + Frugivore			(ns) $F_{(2,33)}$2.65	(ns) $F_{(2,25)}$ 2.2	(ns) $F_{(2,25)}$ 0.67	(ns) $F_{(2,32)}$ 0.87
	TIR	(ns) $F_{(3,41)}$ 1.5	171.70 ± 99.69	8.27 ± 2.62	10.94 ± 3.97	86.47±63.76
	JIR	(ns) $F_{(3,34)}$ 0.77	15.92 ± 4.68	19.66 ± 8.16	6.4210 ± 3.34	54.14 ± 40.85
	WIR(	ns) $F_{(3,40)}$ 0.6	3.39 ± 1.05	6.88 ± 2.22	6.56 ± 1.58	6.25 ± 2.98
Insectivore + Graminivore			(*)$F_{(2,33)}$4.37	(**) $F_{(2,25)}$ 6.44	(ns) $F_{(2,25)}$ 1.18	(ns) $F_{(2,32)}$0.46
	TIR	(ns) $F_{(3,41)}$ 0.93	142.20 ± 66.39	17.290 ±6.04	88.170 ± 37.07	215.50 ±142.4
	JIR	(ns) $F_{(3,34)}$ 1.03	5.62 ± 2.59	1.4 ± 1.4	30.50 ± 14.65	101.10± 81.6
	WIR	(*) $F_{(3,40)}$ 3.69	1.04 ± 0.8	0.31 ± 0.31	112.80 ±39.400	98.70 ± 47.49
Insectivore + Carnivore			(ns) $F_{(2,33)}$ 0.54	(ns) $F_{(2,25)}$0.89	(ns) $F_{(2,25)}$0.89	(ns) $F_{(2,32)}$0.3
	TIR	(ns) $F_{(3,41)}$ 0.33	0.63 ± 0.63	0.75 ± 0.75	0	0.63 ± 0.63
	JIR	(ns) $F_{(3,34)}$ 0.43	0.94 ± 0.94	0	0	1.02 ±1.02
	WIR	(ns) $F_{(3,40)}$ 0.68	0	0	0.31 ± 0.31	0.26 ± 0.26
Omnivore + Frugivore			(ns) $F_{(2,33)}$0.07	(ns) $F_{(2,25)}$0.32	(ns) $F_{(2,25)}$1.53	(ns) $F_{(2,32)}$0.96
	TIR	(**) $F_{(3,41)}$ 5.69	3.76 ± 1.13	5.26 ± 1.15	2.05 ± 1.06	0
	JIR	(ns) $F_{(3,34)}$ 1.35	4.68 ± 2.92	4.21 ± 2.96	0	0
	WIR	(***) $F_{(3,40)}$ 8.69	3.91 ± 0.78	3.44 ± 0.73	1.25 ± 0.51	0.26 ± 0.26

Figure 1.1: Distribution of terrestrial birds according to their feeding habits at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)





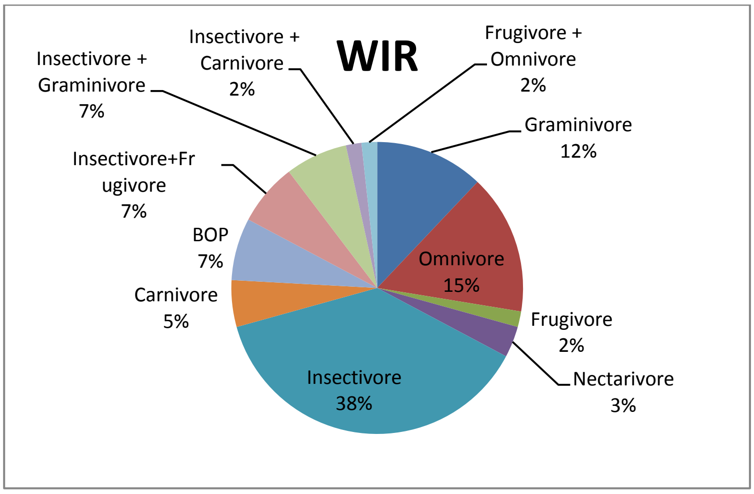


Figure 1.2: Abundance rating of the terrestrial birds encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

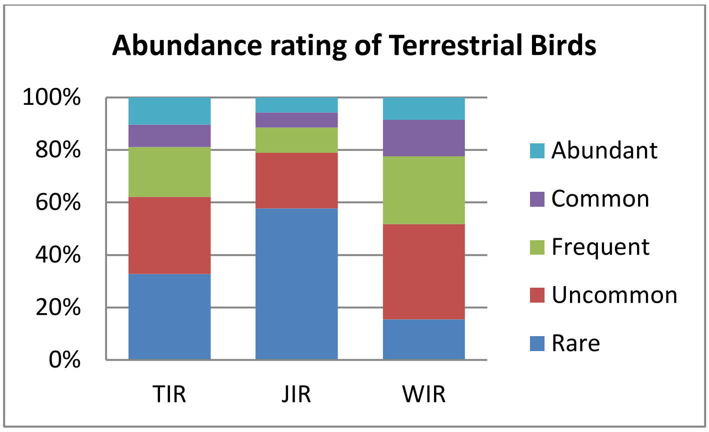


Figure 1.3: Annual Jaccard's similarity Index for terrestrial birds between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

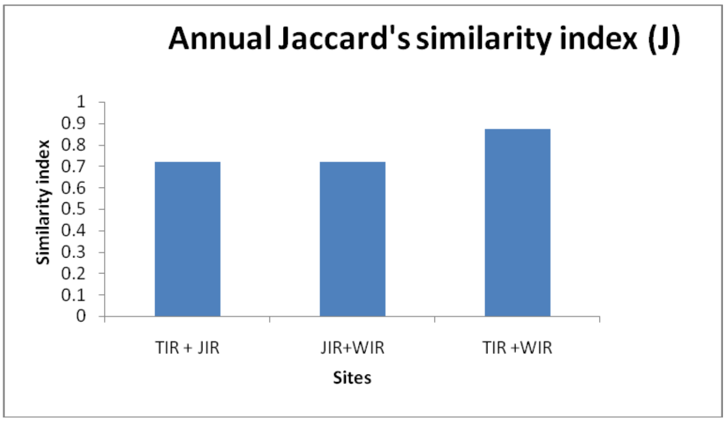


Figure 1.4: Seasonal Jaccard's similarity Index for the Terrestrial birds between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

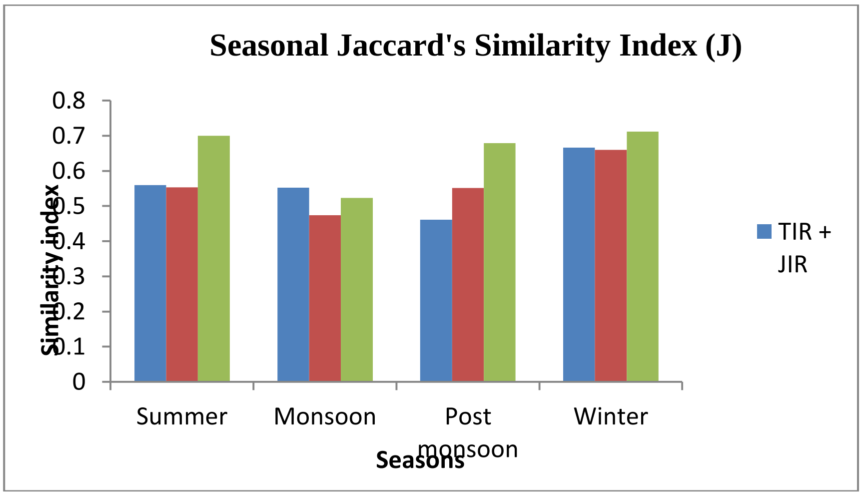
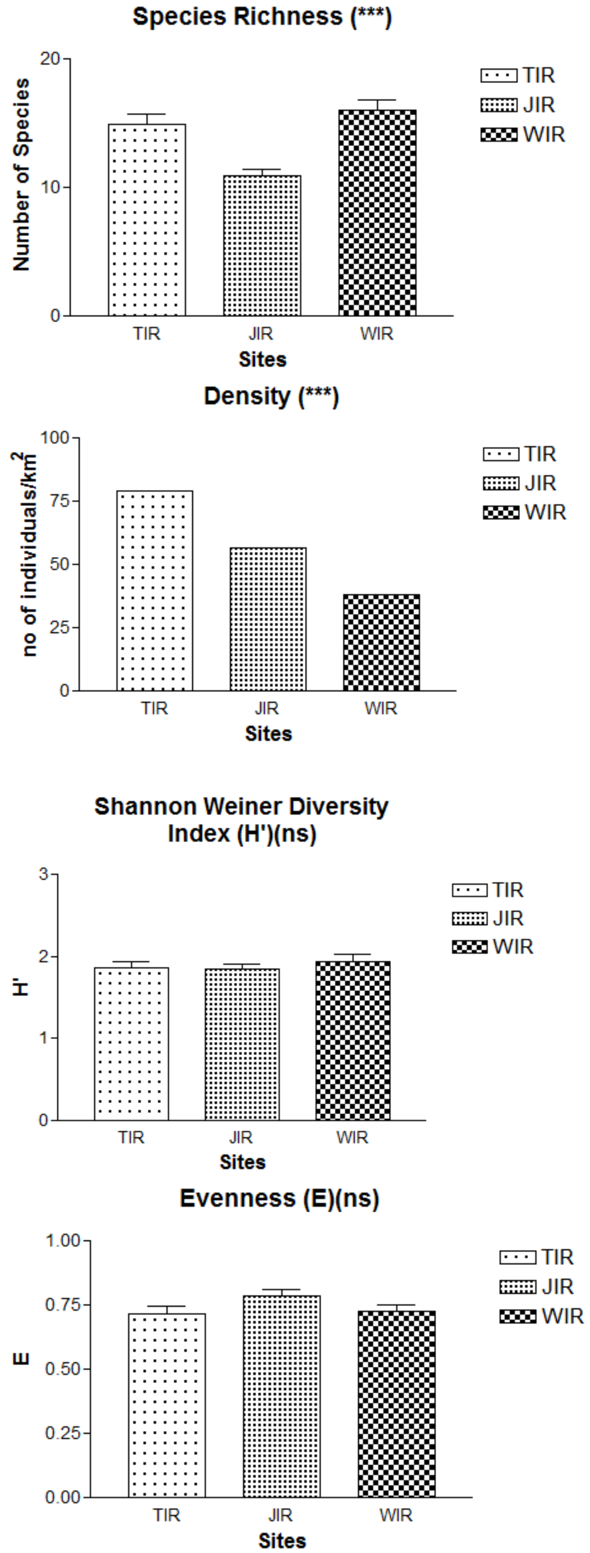
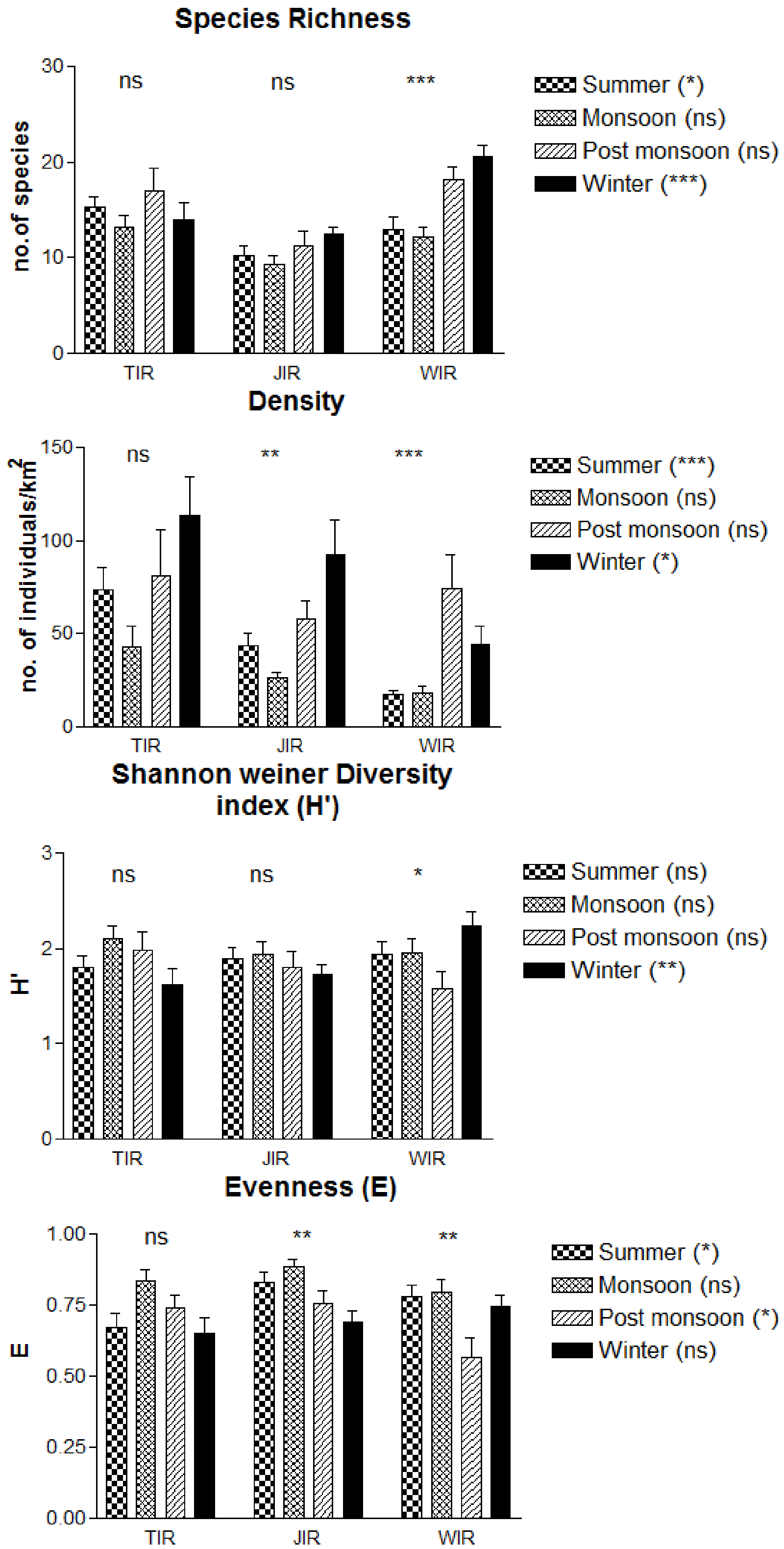


Figure 1.5: Annual differences in the Species Richness, Density, Shannon Weiner Diversity index (H') and Evenness (E) of terrestrial birds at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR).



For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

Figure1.6: Seasonal variations in the Species Richness, Density, Shannon Weiner Diversity index (H') and Evenness (E) of terrestrial birds at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

PLATE - 6 BIRD DIVERSITY AROUND THE THREE RESERVIORS STUDIED

Long tailed Shrike (*Lanius Schach*)

Yellow Wagtail (*Motacilla flava*)

Red Munia (*Amandava amandava*)

Common Stonechat (*Saxicola torquata)*

Birds of Prey

Marsh Harrier (*Circus aeruginosus*)

Osprey (*Pandion haliatus*)

FLOCKS OF TERRESTRIAL BIRDS

Baya Weaver (*Ploceus phillipinus*)

FLOCK OF RED HEADED AND BLACK HEADED BUNTINGS

Discussion

The density and the diversity are dependent on the locations of the study area as well as the seasonal conditions when the study is conducted (Kricher, 1972; 1975; Austin and Tomoff, 1978; Rotenbery, 1978; Rotenberry *et al.,* 1979; Smith and MacMohan, 1981; Nudds 1983; Powell 1987; Bethke and Nudds, 1993). In the present study depending on seasonal changes, variations in the Species richness, density and diversity were found in the terrestrial bird population in the area surrounding the three irrigation reservoirs. The difference in size, the level of human interferences as well as the surrounding land matrix of the three reservoirs selected also produced differences in terrestrial bird density and diversity.

The numbers of factors that influence the presence of a species in a particular habitat are variations in productivity, heterogeneity of abiotic and biotic environments, climatic variations, intensity of predation and environmental age (Cox and Moore, 1993). Amongst TIR and WIR the two reservoirs inundated with Narmada, the terrestrial bird diversity of TIR seems to be influenced by urban expansion due to its presence closer to the Vadodara city while WIR is safer as it is declared as a Nationally Important Wetland as well as it is totally surrounded by agricultural matrix. However, at both the reservoirs same numbers of terrestrial bird species were observed with 87% similarity. At the third reservoir JIR, comparatively low number of terrestrial bird species *i.e.* 52 were observed. This included three species Golden Oriole (*Oriolus oriolus*), Lesser Flameback Woodpecker (*Dinopium benghalense*) and Spotted Owlet (*Athene brama*) that depend on large trees which are present on the earthen dam itself at JIR. This indicate on one hand the difference in habitat at local levels while on the other hand the similarities in climatic conditions around the three reservoirs of the semi arid zone in Gujarat, India.

Feeding Guilds

The role of food quality and availability in the ecology of animals is a well-researched subject (Boutin, 1990). The ability of birds to occupy different habitats in the environment is closely related to their capability to locate and feed on food available in a particular environment (Mahaulpatha *et al.*, 2001). Maximum number of species encountered at the three reservoirs belonged to insectivorous feeding guild, indicating presence of wide diversity and density of insects compared to other food items. Birds stand supreme among vertebrates as depredators of insects (Patel *et al*., 1987; Chakravarthy, 1988; Parasharya *et al*., 1988; 1994, Sivakumaran and Thiyagesan, 2003). Pure insectivores feed only on insects while partial insectivores shift to insectivorous guild with changing environmental conditions. Food has a definite influence on the abundance of birds (Martinez del Rio, 2001). At the three reservoirs ample amount of food is available in the form of insects hence increase in the number of insectivores is apparent. The insectivorous species of birds are known to achieve ecological separation along the resource axes (Martin and Stiles, 1992; Cucco *et al*., 1993).

Habitat change has been implicated in decline of several species across the world. However, the loss of foraging habitats and associated prey species are considered as the major cause for the same. Foraging theory predicts that low availability of prey should act to increase diet breadth through the inclusion of less acceptable foods of low value (Emlen, 1966; Pulliam, 1974; Aktinson and Cade, 1993). Hence, in the times of abundant food resources birds narrow their feeding materials as well as feeding areas so that less energy is used in the foraging and the energy build up can be used for the activities like breeding. Five species of birds found in the area feeding on insects in addition to fruits with 9 omnivore species probably are the species that change their diet according to the availability of food as is discussed by McCarty (1997). Omnivores feeding on a wide variety of food are the generalist species (Teer, 1995) like Crows, Mynas and Babblers that inhabit all the types of habitats and feed on wide variety of food (Grimmett *et al*., 2001) including garbage.

The second most abundant group, the Graminivore, owes its existence to the presence of the agricultural fields and grasses on the earthen dam that provide food for this group of birds. Further, a single Frugivore *P. krameri* found in the study is one of the most common species present in the Indian climatic conditions. *P. krameri* is the major pest of various agricultural crops like Maize, Sunflower, Sorghum and fruits like Guava, Mango, *etc.* (Dhindsa and Saini, 1994). Hence their presence in agricultural matrix with highest density is indisputable. Of the two nectarivore species found in the areas (Padate *et al*., 2001) *Nectarinia asiatica* a common species was present around all the reservoirs while *Nectarinia zeylonica* a comparatively rare species was observed at the undisturbed reservoirs *i.e.* JIR and WIR indicating that they prefer to remain away from disturbances. In Vadodara this species is found only during certain season in the area with good vegetation (Padate *et al*., 2001).

Four carnivores which feed on insects, amphibians, reptiles as well as small mammals along with 5 birds of prey that first capture the living prey and then feast on it get ample food around the wetlands studied. The carnivores in the area include two species of Shrikes*, Lanius vittatus and Lanius schach* along with *Centropus sinensis.* Shrikes are the birds known to prepare the prey before feeding on it. They mostly feed on the insects and small vertebrates captured and impaled on the thorn so that prey is killed and can be distributed in convenient parts to feed. *C. sinensis* - Greater Coucal directly feeds on the captured prey rather than preparing it to feed upon while Birds of Prey mostly hunt on wings and tear the prey with the help of their claws and beak. The bird of Prey observed include *Pandioin haliatus, Milvus migrans, Elanus caeruleus, Circus aeruginosus and Accipiter gentilis.*

Season plays a major role in the food availability and hence seasonal shift in the food is practiced by many species according to the availability of food (Toor and Saini, 1986). Large Grey Babblers feed on insects in monsoon, while on the grains of rice and wheat in their harvest season and shift to plant matter during winter (Toor and Saini, 1986), suggesting that birds change their diet according to the availability in the habitat they live. Tree swallows are also reported to shift their diet from insects to fruits during unavailability of insects (McCarty, 1997) increasing their ability to survive stressful periods. Many partial insectivore species shift to insect food during their breeding season (mainly monsoon) probably due to increased availability of insects and the limited foraging time due to high energy demands of the breeding activities, while shift to either plant matter or seeds during winter as the insect availability decreases (Toor and Saini, 1986). In present study also several species practicing such shifts have been observed which has led to the increase in abundance of birds feeding on insects (Insectivores + Frugivores, Insectivores + Graminivores, Insectivores + Carnivores).

Abundance rating

Community ecology is the study of patterns in assemblages of species (Diamond and Case, 1986). Community ecologists examine commonness and rareness of species, their relationships and stability in community (Pimmentel, 1986), influence of habitat to species diversity (Erwin, 1983; Stork, 1988), and relative abundance of species in habitat with different sizes (Stork, 1988; May 1978). Further, abundance of species is spatially and temporally variable as some species are very abundant, some are rare, and the rest are in between (Ragaei and Allam, 1997). In any habitat the number of common species is always low, while that of the rare species is high (Krebs, 1985) as is also noted at JIR with more than 50% rare species, at TIR with most of them either rare or uncommon and at WIR with majority being uncommon (Table 1.2). Even though the number of rare species is more, their contribution to the density is negligible because these are vagrant species. However, the density of birds is compensated by common species. These species have ability to thrive in any condition and hence built up in masses. The common or abundant species in the area may be compared with the generalist species (Teer, 1995) like Pigeons, Doves, Parakeets, Crows, Mynas, *etc.* which are mostly omnipresent and possess the ability to adapt to a wide variety of environment. The rare species are specialist species requiring particular set of conditions for the survival and multiplication. All individuals of rare species can settle in the habitat for which they are best adapted or are found in other area during their exploring visits quite often in response to seasonal changes. However, abundant species make use of all types of habitat (Alatalo, 1981), slowly adapt to unfavourable habitats and thrive therein. Quite often different individuals of the same species adapt to different habitats (Van Valen, 1965; Roughgarden, 1972) to avoid the intra-specific competition for food resources and shelter.

Jaccard's Similarity Index (J)

As said earlier the higher annual similarity indices (between 72-87%) among the three reservoirs indicate some similarity in the habitats with scrubland and agricultural matrix of semi arid zone since the distance between three reservoirs is 25 -50 Kms and hence movement of birds possible. When seasonal similarity indices are considered the effects of macroclimatic conditions are pronounced in winter when the maximum similarity was noted. This may be attributed to the presence of migratory species and flocking of resident species in the area when vegetation away from water starts drying up in the monsoon dependent semi-arid zone. Likewise in monsoon also macro climatic influences are observed when minimum similarity occurs due to dispersal of birds in wider area when vegetation starts flourishing. Further, in this season as the vegetation grows, visibility decreases, migratory species are absent and many resident species are engaged in nesting activities restricting their movements away from the nesting area. During other seasons the similarity is variable depending on local micro-level habitat differences.

Annual Differences in mean Species Richness, Density and Diversity Indices among the three reservoirs

There are generalist and specialist species present in any ecosystem. The generalist species are able to adapt to varied types of habitats (Teer, 1995; Paraceullos, 2006) and hence are found in all the ecosystems, while the specialist species require a particular set of conditions which may not be available throughout the year forcing them to move away and hence decrease the frequency of their appearance.

According to Patterson (1976), Nilsson and Nilsson (1978), Weller (1978), Murphy *et al.*, (1984) and Krebs (1985), Species richness, density and diversity are the much needed measures for the evaluation of bird populations. The species richness was highest for WIR the largest of the three wetlands. Larger the area more is the number of species present in the area (Krebs, 1985; Rosenweig, 1995; Oertli et al., 2002).Vice versa smaller the size lesser the species richness as is noted for JIR. JIR always showed presence of more common species and hence the specialist species were absent around this reservoir reducing the species richness.

The density of terrestrial birds was highest at TIR which has scrubland like habitat where the birds could hide as well as wait to capture the prey. Comparatively, the other two wetlands have open agricultural matrix with shifting cropping patterns. The presence of generalist urban exploiters like Crows and Mynas (Rathod, 2009) in higher numbers may have led to the higher density around TIR. At the larger reservoir there are high chances of dispersion over a large area even with smallest disturbances leading to lower density. At the third reservoir JIR too, the shrub composition is comparatively dense leading to availability of more space for the birds to hide and rest and hence comparatively higher density than WIR.

The non-significant differences in H' and Evenness among the three reservoirs indicate that the species present in the area are utilizing the habitat equally well. The results of the study conducted by Deshkar (2008) on water birds suggested that the smaller wetlands with low species richness showed higher diversity index compared to the larger wetland with higher species richness. The results of the present study on terrestrial birds do not show any such relation of the size of the wetland with the diversity index.

Unlike the temperate, in tropics food availability is not completely governed by the seasonal influences as the temperature differences are not extreme, hence certain populations of the resident species are present all throughout the year and get adapted to the available food resources. However, the seasonal variations in the density do occur.

Seasonal Differences in the mean Species Richness, Density, Shannon Weiner diversity index (H') and Evenness (E)

The seasonality of rainfall and abundance of the food resources result in the seasonal changes in the species abundance of birds (Karr and Roth, 1971; Gaston *et al.,* 1999; Aynalem and Bekele, 2008). The vegetation composition that depends on seasonal changes also play a major role in determining the distribution and abundance of species (Lee and Rotenberry, 2005; Aynalem and Bekele, 2008). As all species are not equal with regard to their ecological functions (Tilman and Downing 1994) variations in species richness can strongly affect ecosystem properties (Bengtsson *et al.* 1997).

The higher species richness of terrestrial birds that occurred at TIR in post-monsoon was mainly due to the presence of some of the insectivorous birds like House Swift (*Apus affinis*), Blue tailed Bee-eater (*Merops philippinus*), Small Green Bee-eater (*Merops orientalis*), Common Hoopoe (*Upupa epops*), Crimson breasted Barbet (*Megalaina haemacephala*), Rufous tailed Lark (*Ammomanes phoenicurcus*) *etc*. which get ample food when the insects are abundant. Majority of these species disappear in winter as their food become scarce and they have to search for alternative food resources. However, at

WIR almost same species that were present at TIR in post monsoon were present in winter. These species remained around the larger reservoir with several microhabitats and hence no effect on species richness was observed in succeeding season- the winter. The presence of the Birds of Prey which can easily prey on the juveniles as well as adult water birds added to the species richness in winter at WIR.

During summer, larks were numerous influencing the species richness at TIR. In addition, birds like Shrikes and Baya weaver observed in early summer increased the species richness of terrestrial birds in summer at TIR.

During monsoon the species richness was lowest at the three reservoirs because of the absence of all the birds of prey and members of family Ploceidae and Motacillidae either due to their involvement in breeding activities or dispersal resulted from the ubiquitous availability of food. Monsoon rains lead to emergence of many insects and large number of vertebrates also appears due to maximum vegetation growth and hence the most favourable conditions prevail for all these organisms. This creates favourable conditions for many birds to breed when food is available everywhere in large amount and hence they do not need to move in search of food.

Food is frequently the most important density determining factor for birds (Lack, 1966). Higher the availability of food in a habitat higher the density of birds, and lower the food available lower is the density. But, in the present study, although sufficient amount of food was available at WIR the lowest density of terrestrial birds was recorded compared to other two reservoirs. As said earlier, this can be due to the dispersion effect over the wider area. At TIR, the smallest reservoir in size, the maximum density is probably due to the low possibility of dispersion over a smaller area where birds could be easily observed.

When seasonal difference are considered, the highest density observed during winter at TIR and JIR was due to the presence of the species like *P. krameri*, *Emberiza bruniceps*, *E. melanocephala*, *Ploecus philippinus*, *Hirundo rustica*, *H. smithii* and *Passer domesticus* which are gregarious. However, the highest density observed in post monsoon at WIR was due to the early arrival of the migratory populations of Swallows, Buntings and Baya weavers.

The values of mean diversity index - H' and mean Evenness - E in different seasons indicate no particular trend for TIR and JIR for terrestrial bird species. This reveals the site fidelity of majority of species all throughout the year. In the community with more species, heterogeneity is high (Krebs, 1985). However at WIR the seasonal variations in all parameters like species richness (***), density (***), Shannon Weiner diversity index -H' (*) and Evenness - E (**) varied at different levels over the seasons as a result of aggregation of terrestrial birds in the area during post-monsoon and migratory species during winter. Mean evenness around the three reservoirs over the seasons with mean species richness indicates that low species richness led to higher evenness and vice versa as is also reported by Deshkar (2008). When the species present are equally distributed the population is said to be even. Low evenness is considered to be general characteristics of either early succession or of ecosystem containing opportunistic species (Krisher, 1975). All the three reservoirs are constructed more than five decades ago and have established their own ecosystem. Hence latter possibility is true.

As per Connor *et al.* (2000) local population density increases with site area within systems of naturally and experimentally created habitat patches. Elton (1933) defines this site area with reference to a resource. When density is considered without reference to habitat type or resources, density tends to decrease with increase in area as an inverse power function (Smallwood and Schonewald, 1996; Gaston and Blackburn, 2000). In the present study also a decrease in density has been found when specific resources are not taken into consideration.

In case of Water birds, larger the wetland more is the species diversity and Evenness (Aynalem and Bekele, 2008). In the present study, major differences in the diversity indices and evenness were not evident. In natural habitats where the intervention of humans is minimum, the diversity as well as evenness of species is higher (Rana, 2005). Variation in the food and feeding habitats also influence the diversity, evenness and species richness (Smith, 1992). Presence of ample food resources at the three wetlands led to the overall good density and diversity.

Groups of Terrestrial Birds

The highest density of Graminivores at TIR was because of the presence of common birds like *C. livia*, *P. domesticus* and *E. bruniceps*. *C. livia* and *P. domesticus* were the regular species encountered all throughout the year while *E. bruniceps* was the migratory species mostly found during post- monsoon and winter in flocks influencing the density of Graminivores. Cereals and grains are the basic food items of these birds and during their harvesting more population is detected as they aggregate in a place where more food is available (Rana and Idris, 1986). During these seasons the annual grasses start drying leaving the seeds behind for the graminivores. The population of Graminivores was almost constant during rest of the year owing to the moderate populations of Pigeons and Doves.

At JIR also the higher density of Graminivores during winter was due to the presence of flocks of *E. bruniceps* and *E.melanocephala*. During other seasons the density was relatively low due to isolated or desolate presence of majority of the species and the absence of larger flocks. At WIR the density of Graminivores was lower as compared to other two reservoirs because of the low density of the common species like Pigeons and Doves as well as the Buntings. However, the highest seasonal density of Graminivores was due to higher proportion of *P. domesticus* in post-monsoon while both the migratory species of Buntings during winter. Hence it can be said that Buntings were major density contributors around all the three reservoirs in winter. Both the bunting species together form large flocks and are gregarious feeders destroying the standing crop in winter (Grimmett *et al*., 2001). Whether they are destroying crops in the area needs to be investigated.

Other Graminivores like Pigeons and Doves have mostly adapted to the urban habitats as they are fed by man at many spots (Rathod, 2009) and hence they do not form large flocks at remote places far from the human habitation.

Omnivores with high density at JIR compared to other two reservoirs owe their numbers to the larger population of the *C. splendens* and *A. tristis*. These species feed on virtually any available food and were present in large numbers. The seasonal differences in omnivores were not significant with more or less similar density all throughout the year. Around TIR, only House Crow were present with higher density while Common Myna, Indian Peacock (*Pavo cristatus*) and Large Grey Babbler had moderate density with other omnivores in minority. Around this reservoir the density was overall low compared to JIR in winter due to complete absence of the group especially during December in both the years. However, the lowest density of omnivores recorded at WIR in all seasons can be attributed to its distance from urban environment and hence stereotypic food availability. However, WIR is visited by large numbers of visitors during winter who leave behind heaps of garbage an easy food supply attracting the species like Crows and Mynas that influenced the density marginally. House crow has adapted to all types of urban (Rathod 2009) and rural habitats as it is an omnivore scavenging on the waste produced by humans. Hence, lower density of this species at WIR compared to the other two reservoirs TIR and JIR where human intervention is more common. Mynas are gregarious birds foraging in large flocks. Common Myna and Bank Myna are known to feed on variety of food and get their name *Acridotheres* due to their favourite food being the Acridiid Grasshoppers hiding in the grasses (Ali and Ripley, 1983; Mahabal and

Bastawade, 1991). Dhandhukia *et al*., (2011) have reported their large aggregations in the urbanized areas and hence their numbers were higher at JIR and TIR compared to the less disturbed WIR.

Although Frugivores were represented by a single species Rose-ringed Parakeet (*Psitticula krameri*), its density was highest at JIR due to the presence of larger flocks. This species is most widely distributed species of parakeet (Forshaw, 1981) as well as most successful colonizer of new habitats (Long, 1981). It is very common bird of India found in all types of habitat and is reported to be the worst pest in the Indian subcontinent (Ali *et al*., 1981; Shafi *et al*., 1986; Dhindsa and Saini, 1994; Gupta *et al*., 1998; Khan *et al.,* 2006). TIR and WIR had moderate density of this Frugivore. At TIR mostly the surroundings have presence of the scrubs which is not suitable for foraging, while low density at WIR was due to very large area leading to dispersion of this species as well as agricultural matrix producing more rice and wheat crops less preferred by this species. The highest density of this group at different sites was recorded in different seasons, *i.e.* at TIR and JIR in winter while at WIR in summer reflected as presence of the resources in the various seasons. Parakeets are mostly known to be vegetarian, feeding on the vegetarian diet available in the urban landscape as well as fly several miles to forage in farmlands and orchards that facilitate its range expansion and increase in population. David (2011) reported that fruit eating birds do not exclusively feed on fruits but fruits form a major portion of their diet. They supplement their fruit diet with lots of non-vegetarian food. However, no such information is available for this major agricultural pest *P. krameri* of India.

Of all the food resources, nectar is perhaps the most easily quantified resource (Stiles 1995). At TIR only single nectarivore *i.e. N. asiatica* was observed while at JIR and WIR *N. zeylonica* was also present. Due to the infrequent encountered of these species, their overall density was low. However they were frequently observed at JIR compared to other two reservoirs. For nectarivores, flower nectar being deficient in proteins, lipids and other essential nutrients (Baker and Baker, 1982), other alternative food resources rich in protein are essential (Stiles 1995). The protein requirement can be fulfilled by the fruit juices and insects (Klasing, 2004; Ghadirian *et al.*, 2007). In the study on Hummingbirds by Stiles (1995), it was found that they feed on arthropods to fulfill their protein requirements. Sunbird is known to time its breeding according to the insect availability to feed their growing young ones (Ghadirian *et al.*, 2007).

Insectivore is the group with high density around all the three reservoirs. The selected study areas are the habitats surrounding the water body where many insects depending on the aquatic habitat during some stages of their lifecycle are found (Chapter-2 to Chapter -6) and hence the numbers as well as the density of insectivorous birds were higher. The primary prey base available for this group of birds was the Dragonflies and Damselflies (Chapter -3) that occur in large numbers around the reservoirs. They are the main food for the birds of family Hirundinidae (Swallows), Dicruridae (Drongos) and Meropidae (Bee-eaters) that occurred with the higher density in the area. However, because of their keen vision odonates are mainly preyed upon by only few swift fliers that have ability to capture prey in air (Johnson, 2000). Although Swallows are thought to prey on flying prey, they primarily prey on the large aggregations of flying insects that seldom separate from their flocks (Johnson, 2000).

A large number of Hymenopterans (mostly Ants) encountered in present study (Chapter-6) formed the prey base for the Ground feeding birds like Pipits and Wagtails while the phytophagous larvae of insects present on the herbs and shrubs formed prey base for arboreal insectivores like Barbet and Larks. On the whole higher density of the insectivores in the area was principally due to the presence of the members of families Hirundinidae (Swallows) and Dicruridae (Drongos) that catch the prey in air. Pipits that feed on insects present on ground also contributed to the density especially during winters.

Due to prey choice and microhabitat selection, the abundance of arthropods in an environment does not necessarily correspond to the amount of the food available for a foraging bird (Johnson, 2000). For a particular species, only some prey species present in the environment are encountered and of those also only few are considered as the potential food item (Wolda, 1990). Insectivore does not search for food in all microhabitats and the one it does may not be visited too frequently (Hutto, 1990). Hence, many prey items present in the environment may not be available for the insectivore as food items (Cooper and Whitmore, 1990). Wolda (1990) defines food availability as "the abundance of potential prey items in the microhabitats used by the insectivores when searching for food". However, Insectivorous birds have been shown to have direct effects on abundance of herbivorous arthropods by controlling their population (Strong *et al*., 2000) and hence increase plant growth and reduce insect damage (Holmes *et al*. 1979; Kroll and Fleet 1979).

Around the three reservoirs higher densities of the *D. macrocercus*, *H. concolor, H. rustica, H. smithii, H daurica* and *M. philippinus* contributed to the total density of terrestrial birds. In addition to these species, Indian Robin (*Saxicoloides fulicata*) and Paddyfield Pipit (*Phylloscopus collybita*) contributed in the higher density at TIR, while Motacillids with Common chiffchaff (*Anthus rufulus*) and Paddyfield Pipit at WIR and *A. affinis* at JIR.

Various species of birds are reported to prefer different groups of insects for example Small bee-eater, a pure insectivore, is reported to feed on beetles and Hymenopterans (Asokan, 1998), along with Lepidopterans and Odonates, (Mathew *et al*., 1978) and exclusively on Hymenopterans in Africa (Fry *et al*., 1984). Similarly, Blue tailed Bee-eater is known to feed on dragonflies and damselflies as well as other flying insects near the water bodies like irrigation tanks, reservoirs and canals (Grimmett *et al*., 2001). The densities of *M. phillipinus* was observed to be high in monsoon and post monsoon when the densities of flying insects was also high (Chapter 3, 5 and 6) at all the three reservoirs.

Similarly Black Drongos feed mostly on Grasshoppers and Locusts (Hussain and Bhalla, 1937) as well as Coleopterans, Hemipterans and Hymenopterans (Mathew *et al*., 1978; Asokan *et al*., 2009). These insects prey are known to form principal food for many birds due to their easy availability in all habitats (Asokan *et al.*, 2009). Swallows are known to prefer cultivation or open lands near water bodies (Grimmett *et al*., 2001). These gregarious birds feeding in large mixed flocks on the swarms of insects were found in large number in post-monsoon and winter frequently perching on the electricity cables around the reservoirs.

Greater Coucal and Shrikes representing the Carnivore group were always encountered in one and twos and never in large numbers reducing their overall density. These species on top of the ecological pyramids are always found in low numbers. However, the density was little higher at JIR due to higher frequency of Greater Coucal than at other two reservoirs. Greater Coucal prefers grasslands, scrub jungle, shrubberies in cultivation and thick covers adjacent to wetlands (Grimmett, 2001). Hence, these were present around the reservoirs in the semi arid zone. Shrikes are also normally found in the scrub with agricultural cropland (Pande *et al.*, 2004), hence they were reported at all the three habitats which are mainly scrublands surrounded by agricultural fields. They are important as indicator species of environment degradation and the status of grassland communities (Hands *et al*., 1989; Fuisz and Yosef, 1998).

Birds of Prey were also in low density. Many of them were observed during specific season of the year. At TIR they were more frequent in post-monsoon while around JIR in monsoon and around WIR during winter. The higher density in the respective seasons and respective places is attributed to the presence of Black kite (*Milvus migrans*) at TIR and JIR while Osprey (*Pandioin haliatus*) at WIR. Raptors are mostly solitary birds (Grimmett, 2001) and hence might not be found in larger numbers. However, Black Kite is the most common raptor in urban India which exhibits colonial roosting. They are opportunistic hunters and also likely to scavenge. *Milvus migrans govinda* prefers urban areas more frequently than the forested areas (Galushin, 1971). The higher frequency of Black kite at TIR may be due to its closer distance to the Vadodara city, while the higher presence at JIR due to expanding Savli town which is only 2 Kms away from the reservoir. Their population increases in monsoon (Mahabal and Bastawade, 1985; Rathod, 2009). Black-shouldered Kite was also more frequently observed at JIR as it prefers dry scrublands and grassland interspersed with cultivation patches (Grimmett *et al.*, 2001) which is a habitat present around JIR. The third species Osprey feeds principally on fish and hence is known to live around water bodies like rivers, reservoirs, *etc.* (Grimmett *et al.*, 2001). WIR being a large wetland as well as being given on lease for fishing has a large number of fishes and hence could supplement ample food to this species. Osprey is generally present all throughout winter around WIR. Marsh Harrier is another species very commonly observed around wetlands in the semi arid zone of Gujarat with few species of eagles. However as these are late risers they were not encountered during early hours of the study.

The highest density of Insectivore + Frugivore around TIR was because of the presence of Rosy Starling (*Sturnus roseus*) which is colonial bird found in huge flocks. In winter and early summer this species was present around TIR increasing the density while in monsoon and post- monsoon they were absent. The highest density of Rosy starlings was noted at TIR in early summer when they form pre-migratory flocks in huge numbers. Vadodara city has 2 to 3 pre-migratory roosts of thousands of Rosy Starlings. They were encountered rarely at JIR and WIR, the reservoirs away from Vadodara city. At JIR the density of this group in winter was due to the presence of Brahminy Starlings (*Sturnus pagodarum*), few Rosy Starlings and Red vented Bulbuls (*Pycnonotus cafer*). During rest of the year these species were rarely encountered. At WIR the density of this group was low all throughout the year because of the rare appearance of all these species. Red vented bulbul is principally known to be influenced by tall vegetation (Vijayan, 1975), hence not found frequently in the areas with low vegetation. Brahminy Starling is found in dry forest, scrub jungle cultivation (Grimmett *et al*., 2001) and also close to human habitations with vegetation cover. As this species is known to occur singly or in pairs it was not observed in larger numbers.

Though Insectivore + Graminivore feeding guild was occupied by only 4 species of birds, the density of this group was high due to the presence of Baya Weaver (*Ploceus philippinus*). TIR had its highest density throughout the year. This species exhibits a flocking behaviour in winter hence at JIR the highest density of this group was present only in winter. In addition, encounter of the Grey Francolin (*Francolinus pondicerianus*) a ground feeder also increased in winter when vegetation in which they hide started drying up. During summer they probably move to sheltered areas while in monsoon they hide among vegetation leading to their low encounter. The Grey Francolin is usually found in shrub land, savannas, and areas with *Prosopis juliflora* in dry and low elevation; often in human altered environment (Mahmood *et al*., 2010). They are frequently seen along roadsides at dawn or dusk (Scott *et al.*, 1986; Pratt *et al*,. 1987) and around the permanent water bodies in summer and fall (Roberts 1991).

At WIR, density of Insectivores + Graminivore was higher in post-monsoon and winter again due to the presence of flocks of Baya weaver with Streaked weaver (*P. manyar*), while only Baya weavers were noted in winter. Weavers roost communally in winter (Grimmett *et al.*, 2001). They are also known to feed on the rice crop and hence colonize around the areas where rice is cultivated. They prefer grasslands and scrublands with scattered trees to perch which is the habitat present in the study area. These were seen feeding in large numbers in the fields surrounding the reservoirs in months of November -December and hence their larger densities were observed during these seasons of the year. Another species of this guild observed around WIR is Ashy crowned Sparrow-Lark (*Eremopterix grisea*). It is usually found in pairs or in small flocks in the Open lands and scrubs feeding on the grains and insects present on the ground (Grimmett *et al.*, 2001).

Insectivore + Carnivore guild represented by a single species Indian Roller (*Coracias benghalensis*) occurred in low density as it was observed rarely all throughout the year. Indian roller is known to favour agricultural lands and feed on insects (Sivakumaran and Thiyagasen, 2003). It has been reported to be potent bio-control agent (Parasharya, 1994). Its density has probably decreased in recent years and hence needs to be studied carefully.

Omnivore + Frugivore represented by the single species Asian Koel (*Eudynamys scolopacea*) was observed rarely in post-monsoon and winter while sometimes in summer and monsoon. It is a shy species and needs trees for hiding. This species is concealed in the dense foliage when not feeding (Grimmett *et al*., 2001) and hence the rate of their encounter decreases. It is also a common urban adaptor and observed in cities more frequently.

Concluding Remark

Although the density and diversity of the terrestrial birds is low when compared to the wetland birds, they are present in considerable numbers at the eco-tones between wetland and terrestrial land. Different types of the food available in the vicinity of the reservoir encourage the presence as well as colonization of terrestrial birds in the areas surrounding wetlands. The study proves that though the wetland birds are main components of wetland ecosystem, terrestrial birds present in the area form an important component at the eco-tones between wetland and terrestrial land.

INSECT DIVERSITY AROUND WETLANDS

About one million insect species are known to inhabit each and every terrestrial and freshwater niche on the planet Earth. Taxonomically, Class Insecta represents the most diverse and largest group of invertebrates with 70% of the total invertebrate fauna (Dana and Ross, 2004; Rajagopal *et al.*, 2011). They dominate the terrestrial ecosystems in terms of species, biomass and number of individuals, and also ecological roles (Ricklefs *et al*., 1984; Wilson, 1987; 1988). There are about 61,500 known species of insects in India.

Equipped with the diverse modes of lifestyles and ecological requirements during different stages of lifecycle, insects have an edge over most other organisms in resource utilization potential (Arun and Vijayan, 2004). Their success is attributed largely to the evolution of flight, which has facilitated their dispersal, escape from predators, and access to food and adaptation to various environmental conditions (Ragaei and Allam, 1997). Insect diversity has great potential for understanding ecosystem as measures of ecosystem health (Ahmed *et al*., 2004) and hence is particularly useful in the evaluation of landscapes for biological conservation (Kim, 1993; Samways, 1994). However, traditionally, majority of studies use vascular plants and vertebrates as indicator taxa (Alonso and Agosti, 2000) and insects are overlooked in biological inventories (Dana and Ross, 2004). Nevertheless, in recent years the importance and appropriateness of using invertebrate groups has also been recognized (Pearson, 1994; Oliver and Beattie 1996).

Insects are important components of the food chain and food web as they form excellent prey base (Chakaravarthy *et al.*, 1997; Jana *et al.*, 2009) and they are also robust consumer feeding on all types of substances ranging from protozoan to most complex mammals and even dead and decaying matter (Richard and Davies, 1984; Wigglesworth, 1964, Ragaei and Allam, 1997). Owing to their great numbers as well as variety, they are dominant components of many productive as well as decomposing food webs. The biomass of insects exceeds that of the more evident birds and mammals above the surface of earth.

Since environmental quality has become a major concern, insects have occasionally been utilized as valuable indicators of ecological conditions (Baumann, 1979, Ragaei and Allam, 1997). Insects play significant role in the smooth functioning of ecosystems and are natural cleaners playing a vital role in the circulation of the energy and matter. In recent years emphasis is made that insects, along with other invertebrates should be included in biodiversity studies because of their high diversity and rapid response to the environmental changes (Kim, 1993; Kremen *et al.*, 1993; Miller, 1993; Samways, 1994; Basset *et al*., 1998; Longino *et al*., 2002). Documenting insect diversity and understanding how herbivorous insect communities respond to the climate change is important for several reasons. Firstly, herbivore insect comprise a major portion of global biodiversity, representing approximately 57% of 1.75 million described species (Price, 2002). Scientists believe that there may be about nine million insect species waiting to be discovered. Secondly, these herbivores have significant impacts on productivity, decomposition, nutrient recycling and other important ecosystem-level processes (Kremen *et al*., 1993). Thirdly, many insect herbivores are highly mobile, and are expected to migrate rapidly in response to shifting climatic zones (Andrew and Hughes, 2005).

Insect communities can be thoroughly sampled within a relatively short time period (Erwin, 1982; Gullan and Cranston, 2000). Their comparatively smaller size, makes them sensitive to the temperature and humidity variations (Deutsch *et al*., 2008), and their potential for rapid adaptation to environmental changes contributes to their higher species richness (Janzen *et al*., 1976; Gullan and Cranton, 2000, Rahbek, 2005)

Apart from biodiversity documentation, the seasonal appearance of the insect population also has an important role in predicting effects of climate change. Seasonality being a common phenomenon fluctuations in insect populations are caused due to environmental factors like temperature, photoperiod, rainfall, humidity, variation in the availability of food resources, and vegetation cover such as herbs and shrubs (Anu, 2006; Anu *et al.* 2009; Shanthi *et al.* 2009; Tiple and Khurad, 2009).

Terrestrial Insects act as the primary consumers feeding both on terrestrial vegetation and the foliage of the macrophytes in the wetlands (Cahoon and Stevenson, 1986; Foote *et al*., 1988; Goyer *et al*., 1990; Malecki *et al*., 1993) while aquatic insects rarely feed on vascular plants and are most frequently detritus feeders. Most of the insects feeding on living macrophytes occur above the water and are generally terrestrial in nature (Bergey *et al*., 1993; Foote *et al*., 1988; Malecki *et al.*, 1993). Apart from providing food for insects, wetland plants also serve as their structural habitat. Marshy areas are the most productive areas for insect, where open water is interspersed with emergent and submergent plants (Batzer and Wissinger, 1996). Although the impact of terrestrial insect herbivory on wetland ecosystem is not studied, its functioning is probably very significant.

As the importance of the insect fauna in an ecosystem is being recognized, documenting their density and diversity in every ecosystem has become important. Preparation of Biodiversity registers stress on documentation of each and every organism present on the earth. As insects are important components of the ecosystem their documentation is also of utmost importance. At the beginning of this study when terrestrial species of birds around a wetland were documented it was found that majority of them depend on insects during some stage of their life. Hence, in the continuation an attempt has been made to document the insect diversity around three reservoirs in the semi arid zone of Central

Gujarat. To find out the prey base available for these birds the density and diversity of all the insects in the area is considered in this chapter.

Results

Total 9 orders of Class Insecta, *i. e*. Orthoptera, Dicytoptera, Isoptera, Coleoptera, Diptera along with Odonata, Hemiptera, Lepidoptera (Butterflies) and Hymenoptera were represented at the three reservoirs. Of these last four represented in higher numbers are considered separately in Chapters 3 to 6 while first five along with only moths of order Lepidoptera are discussed in detail here with overall insect diversity and density.

Number of species (Table 2.1, Figure 2.1, Annexure 2)

Total 188 species of insects belonging to 55 families were observed in the present study. Of the four major orders, Odonata contributed with 45 species belonging to 8 families, Hemiptera with 19 species of 14 families, Lepidoptera with 57 species belonging to 8 families (49 species belonging to 4 families of butterflies and 8 species belonging to 4 families of moths) and Hymenoptera with 36 species belonging to 6 families. The other orders were represented as 7 species of order Orthoptera belonging to four families, single species each of order Dicytoptera and Isoptera, each represented by single family, 13 species of Coleoptera belonging to 6 families and 8 species of Diptera belonging to 7 families.

Among the five minor orders, order Orthoptera was represented by 7 species belonging to 4 families Tettigonidae, Gryllidae, Acrididae and Gryllotalpidae. All these species were represented around WIR, while 3 species belonging to families Tettigonidae and Acrididae were present around TIR and 4 species belonging to families Tettigonidae, Gryllidae and Acrididae around JIR. Family Gryllotalpidae was represented by a single species only at WIR. Family Tettigonidae was represented by three species *Neoconcocephalus ensiger, Microcentrum rhombifolium* and an unidentified species of Ground Grasshopper only at WIR while at other two reservoirs only the latter was observed. Family Gryllidae was represented by a single species of *Gryllus camprestris* observed only at JIR and WIR while family Acrididae was represented by two species *Txyalis turrita* and *Piokilocercus pictus* at all three reservoirs.

Order Dicytoptera represented by a single species *Mantis religosa* of family Mantidae was recorded at all the three reservoirs. Similarly order Isoptera was represented by a single species of termite belonging to genus *Rhinotermes* of family Rhinotermidae.

Order Coleoptera was represented by 13 species belonging to 6 families (Dermestidae, Carabidae, Buprestidae, Curculionidae, Coccinellidae and Meloidae). Of these 11 species representing all six families were present at TIR while 5 species belonging to 5 different families at JIR and 6 species of 6 different families at WIR. Family Dermestidae was represented by a single species *Attagenus sp.* around all the three reservoirs. Family Carabidae was represented by three species at TIR, while a single species at JIR and WIR. *Scaritus subterraneus* was the species common to all the reservoirs while an unidentified species of genus *Scaritus* along with *Anthia sexguttata* were observed at TIR. Family Buprestidae was represented by two species, *Chrysochus sp and Agrilus sp. at TIR* while by a single unidentified species at WIR. It was totally absent at JIR. Curculionidae was represented by three species at TIR while one species each at JIR and WIR. These include *Anthonomus sp.1* common at TIR and WIR while *Anthonomus sp*. 2 and *Aulacobris sp*. present at TIR only. JIR had altogether different Curcilioniid composition which could not be identified further than the family level. Families Cocinellidae and Meloidae were represented by a single species each *Coccinella septempunctata* and *Mylabris sp.* respectively around the three reservoirs.

Eight species of order Diptera were recorded belonging to 7 families - Sacrophagidae, Tabanidae, Drosophilidae, Chironomidae, Culicidae, Calliphoridae and Muscidae. All the 8 species were present at JIR while 6 species belonging to 6 different families and 5 species belonging to 5 different families were observed at TIR and WIR respectively.

Sacrophagidae was represented by a single species of genus *Sarcophaga* at the three reservoirs. Family Tabanidae was represented by *Chrysops sp.* and *Diachlorus sp.* at JIR and only *Chrysops sp* at TIR while family Drosophilidae was represented by a single species of *Drosophila* at both the reservoirs. These two families were not recorded at WIR. However, families Chironomidae, Culicidae, Calliphoridae and Muscidae were represented by a single species each namely *Chironomus sp.*, *Anopheles sp., Calliphora vomitaria* and *Musca domestica* respectively at the three reservoirs.

Of the 8 moth species recorded in the study, 6 species belonging to 3 families were observed at TIR, while 4 species belonging to 2 families and 6 species belonging to 4 families at JIR and WIR respectively. From the eight species of moths representing 4 families - Arctiidae, Noctuidae, Sphingidae and Pyralidae of the order Lepidoptera, *Utetheisa pulchella* belonging to Arctidae was present around all the three reservoirs, while *Syntomis phegea* of the same family was present at TIR and JIR. Three species of Noctuidae, *Achaea janata*, *Helicoverpa armigera* and *Spodoptera litura* were present at TIR and WIR while later was absent at JIR. Family Sphingidae represented by a single species *Pergesa acteus* was recorded only at WIR while Pyralidae was represented by *Galleria sp.* at TIR and *Achroia sp.* at WIR.

Jaccard's Similarity Index (Table 2.2)

The **annual** Jaccard's similarity index for total insects was maximum 0.68 between TIR and JIR while minimum 0.57 between TIR and WIR. For JIR and WIR it was 0.62 (**Figure 2.2**). When the **seasonal** Jaccard's similarity index is considered it was found that these similarity indices were maximum in monsoon with 0.67 similarities between JIR and WIR, 0.61 for TIR and WIR and 0.52 for TIR and JIR. In the following season, post-monsoon, maximum 59% of species were common between TIR and JIR, 55% between JIR and WIR and 47% between TIR and WIR. In the next season winter, 48% of species were common for TIR and WIR, while 45% for TIR and JIR and 51% for JIR and WIR and during summer, maximum 0.52 similarity index was noted between JIR and WIR, while for TIR and WIR and TIR and JIR it was 0.46 and 0.43 respectively (**Figure 2.3**).

MEAN SPECIES RICHNESS (Table 2.3)

When the *Annual mean Species Richness* of total insects is considered maximum 30.69 ± 1.33 species were recorded for WIR while minimum 21.47 ±1.06 species for TIR. At JIR 28.39 ± 1.48 species were present. The difference in the species richness was highly significant ($p < 0.001$, $F_{(2.125)}$ 14.6) **(Figure 2.4).**

Seasonal Species Richness **(Figure 2.5)**

TIR- At TIR mean Species richness of total insects was highest 24.7 ± 3.25 species in monsoon and was maintained at 24.18 ± 1.19 species in post-monsoon and decreased to lowest 17.83 ± 1.21 species during winter. During summer the mean species richness was 19.92 ± 2.07 species. The seasonal differences showed non-significant differences ($p > 0.05$, $F_{(3, 41)}$ 2.73).

JIR – Here, low mean species richness of insects was noted in winter (24.1 ± 2.58 species) and was maintained at 24.83 ± 2.5 species in summer which increased to 32.88 ± 2.71 species in monsoon and reached to 36.14 ± 2.04 species in post-monsoon. The seasonal variations at JIR were significant at $p < 0.01$ ($F_{(3.34)}$ 4.95).

WIR- At WIR, the mean species richness was lowest 27.33 ± 2.71 species in summer which increased to 28.73 ± 3 species in monsoon, reaching to maximum 36.7 ± 2.29 species in post-monsoon and decreased to 30.83 ± 1.97 species in winter. However, the fluctuation in the insect species richness showed non-significant variations ($p > 0.05$, $F_{(3, 41)}$ 2.5).

Among the reservoirs

When the three reservoirs are compared, WIR had higher species richness in summer followed by JIR and lowest at TIR with non-significant ($p > 0.05$, $F_{(2, 33)}$ 2.38) differences. During monsoon, among the three reservoirs, highest species richness was recorded for JIR while lowest for TIR ($p > 0.05$, $F_{(2, 26)}$ 1.65). In post-monsoon almost same mean species richness of insects were observed for JIR and WIR while lowest for TIR with significant differences at $p < 0.001$ ($F_{(2.25)}$ 15.78). In the next season winter, lowest mean species richness was recorded at TIR while highest at WIR. At JIR mean species richness of insects was moderate and the differences among the three reservoirs were highly significant ($p < 0.001$, ($F_{(2.32)}$ 11.32).

MEAN DENSITY

Annual Mean Density **(Table 2.4, Figure 2.6)**

Ground Insects – Quadrat Count Method is used to calculate the density for the insects present on the ground. The highest mean density of ground insects 172 ± 25 individuals/m^2 was encountered at WIR and lowest 115.9 ± 14.81 individuals/m^2 for TIR, while JIR had 138.3 ± 18.96 individuals/m^2. The differences among three reservoirs were non-significant ($p > 0.05$, $F_{(2,125)}$ 2.06).

Arboreal Insects - The density of the insects which resides on the bushes were calculated by bush count method. The insects that were most frequently encountered for density by this method mainly include the ants and Treehopper with some phytophagous hemipteran bugs. The mean annual density of arboreal insects was found to be highest 30.45 ± 7.47 individuals/m^2 at TIR and lowest 21.82 ± 3.42 individuals/m^2 at WIR, while it was 27.03 ± 3.53 individuals/m^2 at JIR. Non-significant differences were noted among the three reservoirs ($p > 0.05$, $F_{(2,125)}$ 0.7).

Aerial Insects –The density of flying insects were calculated using Point Count Method. Lowest mean annual density for flying insects 0.015 ± 0.002 individuals/10m^2/min was recorded for TIR while the highest 0.024 ± 0.003 individuals/10m^2/min for JIR. WIR had 0.021 ± 0.002 individuals/10m^2/min. Non-significant differences were noted among the three reservoirs ($p > 0.05$, $F_{(2,125)}$ 2.66).

Seasonal Density (Table 2.5, Figure 2.7)

Ground Insects

TIR - Maximum mean density of ground insects 157.8 ± 32.25 individuals/m^2 was observed during summer which decreased to 90.94 ± 8.42 individuals/m^2 in monsoon and increased to 126.6 ± 44.1 individuals/m^2 in post-monsoon. In winter minimum mean density 84.96 ± 16.75 individuals/m^2 was recorded. The seasonal differences were non-significant ($p > 0.05$, $F_{(3.41)}$ 1.39).

JIR – Opposing results to that of TIR were observed at JIR with maximum mean density 194.4 ± 57.22 individuals/m^2 recorded during winter and minimum 80.16 ± 14.1 individuals/m^2 in monsoon. During summer and post-monsoon the mean densities were 123.8 ± 15.71 individuals/m^2 and 141.1 ± 29.75 individuals/m^2 respectively ($p > 0.05$, $F_{(3.34)}$ 1.65).

WIR – At WIR, the mean density 150.1 ± 37.94 individuals/m^2 was recorded during summer which was almost maintained at 158.8 ± 55.97 individuals/m^2 in monsoon but decreased to minimum 110.2 ± 20.95 individuals/m^2 in post-monsoon and was observed to increase to maximum 257.5 ± 63.33 individuals/m^2 in winter. However, though an abrupt increase was noted in winter the overall seasonal variations showed non-significant differences ($p > 0.05$, $F_{(3.41)}$ 1.65).

Among three reservoirs

Non-significant ($p > 0.05$) differences were noted between the three reservoirs in all the seasons. In summer maximum mean density was recorded at TIR and minimum at JIR ($F_{(2,33)}$ 0.35). In monsoon highest mean density was noted for WIR while low density for JIR and TIR ($F_{(2,26)}$ 1.3). During post-monsoon highest mean density was recorded at JIR while lowest for WIR with $F_{(2,25)}$ 0.18. In the next season winter the highest mean density was recorded at WIR followed by JIR while lowest at TIR ($F_{(2,32)}$ 3.15).

Arboreal Insects

TIR- Minimum mean density of arboreal insects 2.67 ± 1 individuals/m^2 was recorded during monsoon which increased through post-monsoon (9.88 ± 2.70 individuals/m^2) to winter (46.32 ± 9.19 individuals/m^2) and reached to maximum 56.57 ± 23.81 individuals/m^2 in summer with significant variations ($p < 0.05$, $F_{(3,41)}$ 3.7).

JIR – At JIR, low mean densities 20.72 ± 7.57 individuals/m^2 and 20.63 ± 6.84 individuals/m^2 were noted during summer and monsoon respectively which was maintained during post-monsoon to 23.7 ± 5.3 individuals/m^2 and increased in winter to 40.69 ± 5.43 individuals/m^2 but with non-significant variations ($p > 0.05$, $F_{(3,34)}$ 2.28).

WIR – Low mean density 10.95 ± 2.44 individuals/m^2 in summer was maintained in monsoon and post-monsoon with 13.19 ± 2.93 individuals/m^2 and 13.38 ± 2.36 individuals/m^2 respectively. The density peaked in winter to 47.65 ± 8.7 individuals/m^2. The differences in four seasons varied highly significantly ($p < 0.001$, $F_{(3,41)}$ 12.25).

Among three reservoirs

In summer highest density was observed at TIR while lowest at WIR. At JIR the density was moderate with non-significant ($p > 0.05$, $F_{(2.33)}$ 2.74) differences among the three reservoirs. In monsoon and post-monsoon lowest density were recorded at TIR while highest at JIR, WIR had moderate density in both the seasons with significant differences ($p < 0.05$) and $F_{(2,26)}$ 5.26 and $F_{(2,25)}$ 4.22 respectively. During winter all three reservoirs had higher mean density with comparatively higher density at TIR and WIR but with non-significant differences ($p < 0.05$, $F_{(2,32)}$ 0.2).

Aerial Insects

TIR – At TIR minimum mean density 0.004 ± 0.001 individuals/10m^2/min was recorded during winter. An increase was observed from summer 0.009 ± 0.001 individuals/10m^2/min to monsoon 0.02 ± 0.005 individuals/10m^2/min to maximum 0.03

± 0.006 individuals/10m^2/min in post-monsoon. The differences were highly significant with $p < 0.001$ ($F_{(3.41)}$ 10.7).

JIR- The mean density of aerial insects at JIR was high during summer and Post-monsoon with 0.03 ± 0.007 individuals/10m^2/min and 0.03 ± 0.009 individuals/10m^2/min respectively while it was lowest 0.01 ± 0.004 individuals/10m^2/min in winter. In monsoon, the mean density was noted to be 0.02 ± 0.004 individuals/10m^2/min. The seasonal differences were non-significant ($p > 0.05$, $F_{(3.34)}$ 1.84).

WIR- Mean density of the flying insects showed significant variations at 0.001 with $F_{(3.41)}$ 7.4 at WIR. The mean density oscillated from 0.03 ± 0.005 individuals/10m^2/min in summer to 0.01 ± 0.001 individuals/10m^2/min in monsoon, to 0.02 ± 0.003 individuals/10m^2/min in post monsoon and 0.01 ± 0.002 individuals/10m^2/min in winter.

Among three reservoirs

The differences in the mean density of the flying insects was significant at $p < 0.01$ ($F_{(2.33)}$ 6.39) during summer with higher densities recorded for JIR and WIR while lower for TIR. In monsoon and post-monsoon non-significant differences ($p > 0.05$) were noted between three reservoirs. Higher densities were noted for TIR and JIR in monsoon as well as post-monsoon, while they were low for WIR with $F_{(2, 26)}$ 0.86 and $F_{(2,25)}$ 1.19 respectively. During winter TIR had lowest density while JIR and WIR had higher density with significant differences noted among the three reservoirs ($p < 0.05$, $F_{(2.32)}$ 3.87).

Percentage Occurrence

Annual **(Table 2.6, Figure 2.8)**

TIR – Among the nine orders of class Insecta represented at TIR, highest percentage occurrence 28.36% of the total insects was noted for Odonata which was closely followed by Lepidoptera with 28.26%, Hymenoptera with 22.05% and Hemiptera with

12.63%. Other five orders with very low percentage occurrence were Orthoptera with 1.55%, Dicytoptera with 0.1%, Isoptera with 0.72%, Coleoptera with 3.31% and Diptera with 3%.

JIR – At JIR too, 30% of the total insects present belonged to order Odonata, followed by 28.78% of Lepidoptera, 23.31% of hymenoptera and 10.31% of Hemiptera. Lowest 0.09 % occurrence was recorded for Isoptera while Dicytoptera constituted 0.37%. Orthoptera was represented by 2.41%, Coleoptera by 1.58% and Diptera by 3.16 %.

WIR- At WIR, a comparatively different trend in the percentage occurrence was observed. Here Lepidoptera was represented with 31.48% *i.e.* maximum percentage occurrence, followed by Odonata with 27.5%, Hymenoptera with 20.7% while Hemiptera with 12.23% of the total insect population. Among the low represented orders, Dicytoptera was the order with minimum 0.07%, Orthoptera with 3.33%, Isoptera 0.72%, Coleoptera 1.3% and Diptera 2.68% of the total insects.

Among the Habitats

When the percentage occurrence of the individual order is considered among the three reservoirs it was observed that Odonata, Dicytoptera, Diptera and Hymenoptera had the higher percentage occurrence at JIR while Orthoptera and Lepidoptera at WIR, and Hemiptera and Coleoptera at TIR. Isoptera had same percentage occurrence at TIR and WIR.

Seasonal Percentage Occurrence (Table 2.7, Figure 2.9)

The seasonal percentage occurrence showed that Odonata had an overall higher percentage occurrence around all the three reservoirs with more than 15% occurrence in all the seasons of the year. However, its percentage occurrence was highest during summer. Though Orthoptera and Diptera occurred with low percentage occurrence during all the seasons they were never absent around the reservoirs surveyed. Dicytoptera was represented only during winter at TIR and WIR while during post-monsoon at JIR. Isoptera had very low percentage occurrence and was absent during post-monsoon at TIR and monsoon at WIR, while present only during winter at JIR. The percentage occurrence of Hemiptera varied in different seasons and was found to be highest in winter. Coleoptera had low percentage occurrence and was totally absent during summer at JIR and WIR. Lepidoptera was also one of the dominant insect order with more than 20% occurrence in all seasons around the three reservoirs, however it had highest percentage occurrence during post-monsoon at TIR and WIR while during monsoon at JIR. Hymenoptera also had higher percentage occurrence and was found to dominate during winter at TIR while during summer at JIR and WIR.

Seasonal differences Around Each Reservoir

A different approach is followed to discuss the seasonal differences around the reservoirs. As the percentage occurrence of one group is influenced by that of other groups, the comparison in the differences observed in different seasons is not possible and hence the percentage occurrence of different orders in a particular season at each reservoir is taken into consideration.

Here one should not forget that percentage occurrence is a mathematical calculation where when the percentage occurrence of one order increases, a decrease in the percentage occurrence of other orders groups is noted and *vice versa*.

TIR

Summer – During summer, Odonata dominated over all the insect orders with 35.15% occurrence around TIR. Other orders with higher percentage occurrence were Hymenoptera with 22.59%, Lepidoptera with 20.5% and Hemiptera with 14.23% occurrence while all other groups were uncommon with less than 5% occurrence. Among these, Dicytoptera was totally absent while Isoptera had 0.84%. Coleoptera and Diptera constituted 2.51% each while Orthoptera 1.67% of the total insects.

Monsoon- However, during monsoon, Lepidoptera dominated all the insect orders with 31.58% occurrence followed by Odonata and Hymenoptera with 24.7% and 22.27% respectively. Insect orders with lower percentage occurrence were Hemiptera with 7.29%, Diptera with 6.07%, Coleoptera with 4.86%, Orthoptera with 2.83% and Isoptera with 0.4%.

Post-monsoon –In this season Lepidoptera (37.22%) and Odonata (34.96%) dominated contributing more than 70% of the insect population while Hymenoptera constituted nearly 15% and Hemiptera 7.52%. Isoptera and Dicytoptera were totally absent, while Orthoptera had 1.13%, Coleoptera 1.88% and Diptera 2.26% occurrence.

Winter – At TIR, during winter Hymenoptera was the most dominant group with 29.91% occurrence followed by Hemiptera with 23.36%, Lepidoptera with 21.96% and Odonata with 16.82%. Other orders had low percentage occurrence with 0.47% each for Orthoptera and Dicytoptera while 0.93% for Diptera, 1.87% for Isoptera and 4.21% for Coleoptera. On the whole, winter was the only season when all nine orders of class Insecta recorded over the study were represented at TIR.

JIR

Summer – At JIR also Odonata was the most dominant order with 33.56% occurrence followed by Lepidoptera and Hymenoptera with 28.86% and 27.18% respectively. Dicytoptera, Isoptera and Coleoptera were totally absent during summer while Orthoptera had 0.34%, Diptera 3% and Hemiptera 7% occurrence.

Monsoon – Like TIR, during monsoon, Lepidoptera was the most dominant order with 31% occurrence at JIR closely followed by Odonata with 29%, Hymenoptera 21% and Hemiptera 8.43% of the total insects. Dicytoptera and Isoptera were totally absent while percentage occurrence of Orthoptera, Coleoptera and Diptera each were between 3 to 4%.

Post-monsoon – Odonata had the highest 32.02 % occurrence followed by 29.64% of Lepidoptera, 17.79% of Hymenoptera and 9% of Hemiptera. Other orders were sparsely represented with 3.95% Orthoptera, 1.58% Dicytoptera, 2.37% Coleoptera and 3.56% Diptera. Isoptera was the only order absent at JIR during this season.

Winter –During winter Odonata, Lepidoptera and Hymenoptera had nearly same percentage occurrence with 24.91%, 25.66% and 26.42% respectively. Hemiptera though lower than these orders had higher percentage occurrence in this season compared to rest of the seasons with 16.98%. Dicytoptera was totally absent while Isoptera and Coleoptera had 0.38% occurrence and Orthoptera and Diptera 2.64 % each.

WIR

Summer **–** Odonata was the family represented with highest 34.76 % occurrence in summer around WIR. Lepidoptera and Hymenoptera had almost similar percentage occurrence of 23.48% and 24.09% respectively while Dicytoptera and Coleoptera were completely absent. Hemiptera had moderate percentage occurrence of 11.28%. All other orders had low percentage occurrence with Orthoptera 3%, Isoptera 0.61% and Diptera 2.74%.

Monsoon – Here too as recorded for the other two reservoirs Lepidoptera had the highest 29.43% occurrence during monsoon followed by Odonata with 27.53% and Hymenoptera with 22.78%. Contrary to its total absence during summer, Coleoptera constituted nearly 11.08% of the total population along with Hemiptera. Dicytoptera and Isoptera were totally absent and Orthoptera and Diptera had low percentage occurrence of 3.48% and 4.11% respectively.

Post-monsoon – As noted for TIR, during post-monsoon, WIR also had nearly 70% of the insects contributed by the two major orders Lepidoptera and Odonata with 37.6% and 29.7 % occurrence respectively. Hymenoptera accounted for 15.53 % occurrence while Hemiptera 9.26%. Dicytoptera was totally absent and other orders had low percentage occurrence with 3.81% for Orthoptera, 0.27% for Isoptera and 1.91% for Coleoptera and Diptera each.

Winter - All the insect orders were present during winter at WIR. Lepidoptera dominated with 34.32% occurrence followed by 21% of Hymenoptera, 18.65% Odonata and 17% Hemiptera. Other orders had low percentage occurrence of 2.97% Orthoptera, 0.27% Dicytoptera, 1.89% Isoptera, 1.62% Coleoptera and 2.16% of Diptera.

Comparison among the habitats

When comparisons are made for percentage occurrence of various orders among the three habitats surveyed, it is noted that **Odonata** exhibited negligible differences among the reservoirs in all seasons except winter when it was comparatively higher at JIR. **Orthoptera** which had overall lower percentage occurrence exhibited lowest percentage occurrence at JIR during summer whereas at TIR during other seasons. The next order **Dicytoptera** recorded very low percentage occurrence with absence around all the three reservoirs during summer and monsoon while presence only at JIR during post-monsoon and around other two reservoirs during winter. The next order **Isoptera**, again with very low percentage occurrence amongst the three habitats, occurred at JIR only during winter while was absent at TIR and WIR during post-monsoon and monsoon respectively. **Hemiptera** one of the major order represented around the three reservoirs had comparatively lower percentage occurrence around JIR in summer, at TIR and JIR in monsoon and around all the three reservoirs during post-monsoon, while high percentage occurrence during winter at the three reservoirs. Order **Coleoptera** represented with low percentage occurrence occurred in summer only at TIR but occurred with higher % in monsoon around WIR. Otherwise its percentage occurrence was comparatively lower amongst the 9 orders reported. Order **Diptera** was represented during all the seasons around the reservoirs surveyed but with lower % occurrence. Order **Lepidoptera** and **Hymenoptera** occurred with comparatively higher percentage occurrence all throughout the year around the three reservoirs. However, the later exhibited comparatively lower percentage occurrence, especially in post-monsoon.

Table 2.1: Number of species in each of the nine Insect orders at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Odonata	Orthoptera	Dicytoptera	Isoptera	Hemiptera	Coleoptera	Diptera	Lepidoptera	Hymenoptera
TIR	35	3	1	1	12	11	6	40	20
JIR	37	4	1	1	15	5	8	40	23
WIR	35	7	1	1	17	6	5	48	25
Total	45	7	1	1	19	13	8	57	36

Table 2.2: Annual and Seasonal Jaccard's Similarity Index of Total Insects among Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Annual		Summer		Monsoon		Post-monsoon		Winter	
	TIR	JIR	TIR	JIR	TIR	JIR	TIR	JIR	TIR	JIR
WIR	0.57	0.62	0.46	0.52	0.61	0.67	0.47	0.55	0.48	0.51
JIR	0.68	-	0.43	-	0.52	-	0.59	-	0.45	-

Table 2.3: Mean Species Richness of Insects at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

Species Richness	TIR	JIR	WIR
Annual (***) $\mathbf{F_{(2,125)}}$ **14.6**	21.47 ± 1.06	28.39 ± 1.48	30.69 ± 1.33
Seasonal	**(ns)** $\mathbf{F_{(3,41)}}$ **2.73**	**(**)** $\mathbf{F_{(3,34)}}$ **4.95**	**(ns)** $\mathbf{F_{(3,41)}}$**2.5**
Summer (ns) $\mathbf{F_{(2,33)}}$ **2.38**	19.92 ± 2.07	24.83 ± 2.5	27.33 ± 2.71
Monsoon (ns) $\mathbf{F_{(2,26)}}$ **1.65**	24.7 ± 3.25	32.88 ± 2.71	28.73 ± 3
Post-monsoon (***) $\mathbf{F_{(2,25)}}$ **15.78**	24.18 ± 1.19	36.14 ± 2.04	36.7 ± 2.29
Winter (***) $\mathbf{F_{(2,32)}}$ **11.32**	17.83 ± 1.21	24.1 ± 2.58	30.83 ± 1.97

Table 2.4: Annual Mean Density of Insects at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	TIR	JIR	WIR
Ground Insects/m^2 (ns) $\mathbf{F_{(2,125)}}$ **2.06**	115.9 ± 14.81	138.3 ± 18.96	172 ± 25
Arboreal Insects/m^2 (ns) $\mathbf{F_{(2,125)}}$ **0.7**	30.45 ± 7.47	27.03 ± 3.53	21.82 ± 3.42
Aerial Insects/10m^2/min (ns) $\mathbf{F_{(2,125)}}$ **2.66**	0.015 ± 0.002	0.024 ± 0.003	0.021 ± 0.002

Table 2.5: Seasonal Mean Density of Insects at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

			Summer	Monsoon	Post-monsoon	Winter
Ground Insects		**Among Reservoirs** / **Within Reservoirs**	ns $\mathbf{F_{(2,33)}}$ **0.35**	ns $\mathbf{F_{(2,26)}}$ **1.3**	ns $\mathbf{F_{(2,25)}}$ **0.18**	ns $\mathbf{F_{(2,32)}}$ **3.15**
	TIR	(ns) $\mathbf{F_{(3,41)}}$ **1.39**	157.8 ± 32.25	90.94 ± 8.42	126.6 ± 44.1	84.96 ± 16.75
	JIR	(ns) $\mathbf{F_{(3,34)}}$ **1.65**	123.8 ± 15.71	80.16 ± 14.1	141.1 ± 29.75	194.4 ± 57.22
	WIR	(ns) $\mathbf{F_{(3,41)}}$ **1.65**	150.1 ± 37.94	158.8 ± 55.97	110.2 ± 20.95	257.5 ± 63.33
Arboreal Insects			ns $\mathbf{F_{(2,33)}}$ **2.74**	* $\mathbf{F_{(2,26)}}$ **5.26**	* $\mathbf{F_{(2,25)}}$ **4.22**	ns $\mathbf{F_{(2,32)}}$**0.2**
	TIR	(*)$\mathbf{F_{(3,41)}}$ **3.7**	56.57 ± 23.81	2.671 ± 0.1	9.88 ± 2.7	46.32 ± 9.19
	JIR	(ns) $\mathbf{F_{(3,34)}}$ **2.28**	20.72 ± 7.57	20.63 ± 6.84	23.7 ± 5.3	40.69 ± 5.43
	WIR	(***)$\mathbf{F_{(3,41)}}$ **12.25**	10.95 ± 2.44	13.19 ± 2.93	13.38 ± 2.36	47.65 ± 8.7
Aerial Insects			** $\mathbf{F_{(2,33)}}$ **6.39**	ns $\mathbf{F_{(2,26)}}$ **0.86**	ns $\mathbf{F_{(2,25)}}$ **1.19**	* $\mathbf{F_{(2,32)}}$ **3.87**
	TIR	(***)$\mathbf{F_{(3,41)}}$ **10.7**	0.009 ± 0.001	0.02 ± 0.005	0.03 ± 0.006	0.004 ± 0.001
	JIR	(ns) $\mathbf{F_{(3,34)}}$ **1.84**	0.03 ± 0.007	0.02 ± 0.004	0.03 ± 0.009	0.01 ± 0.004
	WIR	(***)$\mathbf{F_{(3,41)}}$ **7.4**	0.03 ± 0.005	0.01 ± 0.001	0.02 ± 0.003	0.01 ± 0.002

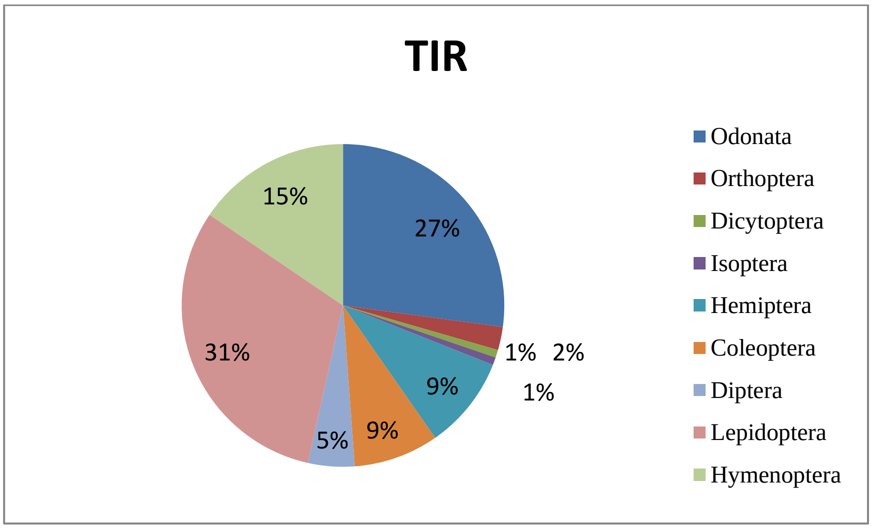
Table 2.6: Annual Percentage Occurrence of nine Insect orders at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

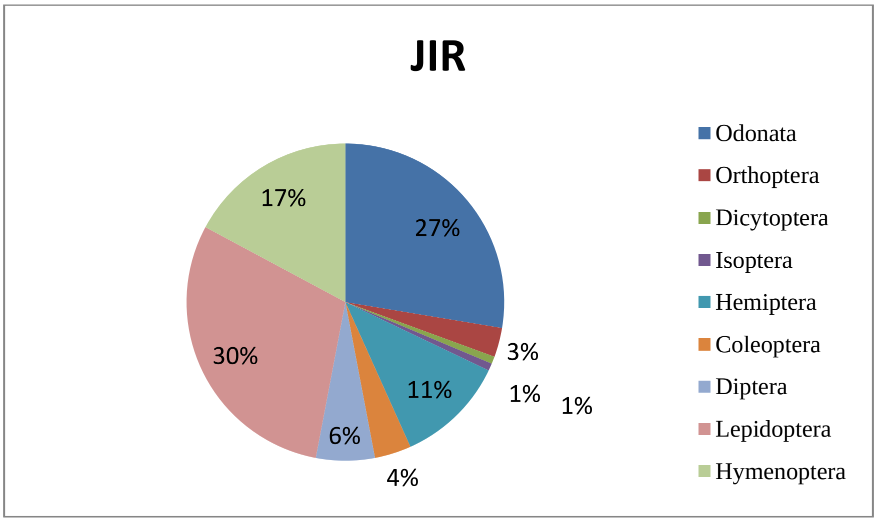
	Odonata	Orthoptera	Dicytoptera	Isoptera	Hemiptera	Coleoptera	Diptera	Lepidoptera	Hymenoptera
TIR	28.36 %	1.55%	0.10 %	0.72 %	12.63 %	3.31 %	3%	28.26 %	22.05 %
JIR	30 %	2.41%	0.37 %	0.09 %	10.31 %	1.58 %	3.16%	28.78 %	23.31 %
WIR	27.5 %	3.33%	0.07 %	0.72 %	12.23 %	1.3 %	2.68%	31.48 %	20.7 %

Table 2.7: Seasonal Percentage Occurrence of nine insect orders at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

Orders	**Sites**	**SUMMER**	**MONSOON**	**POST MONSOON**	**WINTER**
ODONATA	TIR	35.15 %	24.70 %	34.96 %	16.82 %
	JIR	33.56 %	29.12 %	32.02 %	24.91 %
	WIR	34.76 %	27.53 %	29.70 %	18.65 %
ORTHOPTERA	TIR	1.67 %	2.83 %	1.13 %	0.47 %
	JIR	0.34 %	3.07 %	3.95 %	2.64 %
	WIR	3.05 %	3.48 %	3.81 %	2.97 %
DICYTOPTERA	TIR	0.00 %	0.00 %	0.00 %	0.47 %
	JIR	0.00 %	0.00 %	1.58 %	0.00 %
	WIR	0.00 %	0.00 %	0.00 %	0.27 %
ISOPTERA	TIR	0.84 %	0.40 %	0.00 %	1.87 %
	JIR	0.00 %	0.00 %	0.00 %	0.38 %
	WIR	0.61 %	0.00 %	0.27 %	1.89 %
HEMIPTERA	TIR	14.23 %	7.29 %	7.52 %	23.36 %
	JIR	7.05 %	8.43 %	9.09 %	16.98 %
	WIR	11.28 %	11.08 %	9.26 %	17.03 %
COLEOPTERA	TIR	2.51 %	4.86 %	1.88 %	4.21 %
	JIR	0.00 %	3.83 %	2.37 %	0.38 %
	WIR	0.00 %	11.08 %	1.91 %	1.62 %
DIPTERA	TIR	2.51 %	6.07 %	2.26 %	0.93 %
	JIR	3.02 %	3.45 %	3.56 %	2.64 %
	WIR	2.74 %	4.11 %	1.91 %	2.16 %
LEPIDOPTERA	TIR	20.50 %	31.58 %	37.22 %	21.96 %
	JIR	28.86 %	31.03 %	29.64 %	25.66 %
	WIR	23.48 %	29.43 %	37.60 %	34.32 %
HYMENOPTERA	TIR	22.59 %	22.27 %	15.04 %	29.91 %
	JIR	27.18 %	21.07 %	17.79 %	26.42 %
	WIR	24.09 %	22.78 %	15.53 %	21.08 %

Figure 2.1: Species composition of different insect orders at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)





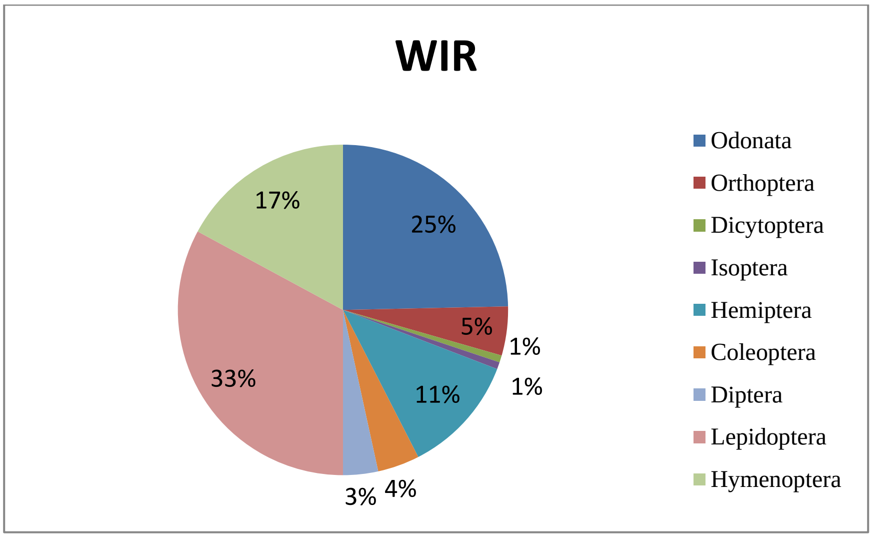


Figure 2.2: Annual Jaccard's similarity Index of Insects between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

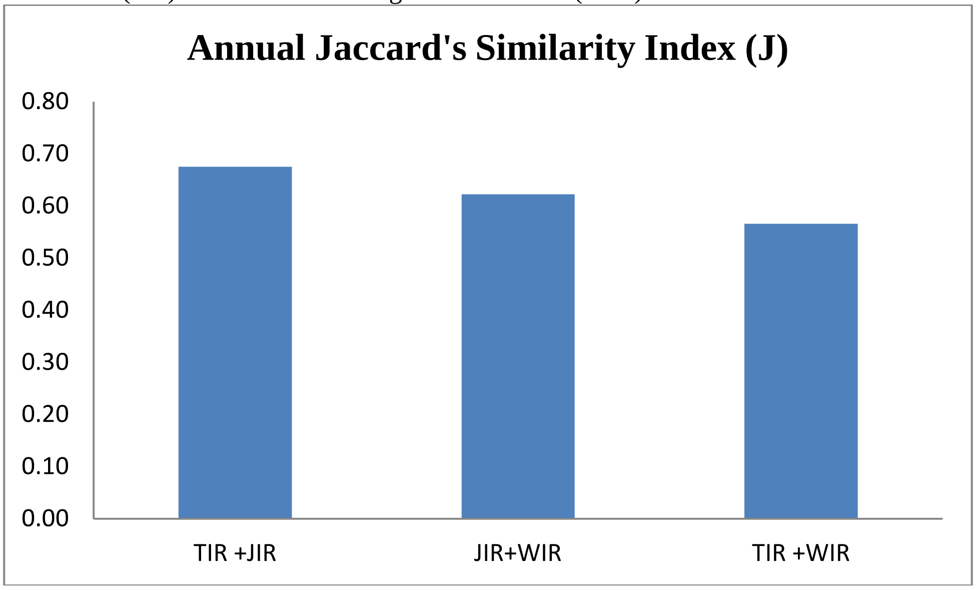


Figure 2.3: Seasonal Jaccard's similarity Index of Insects between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

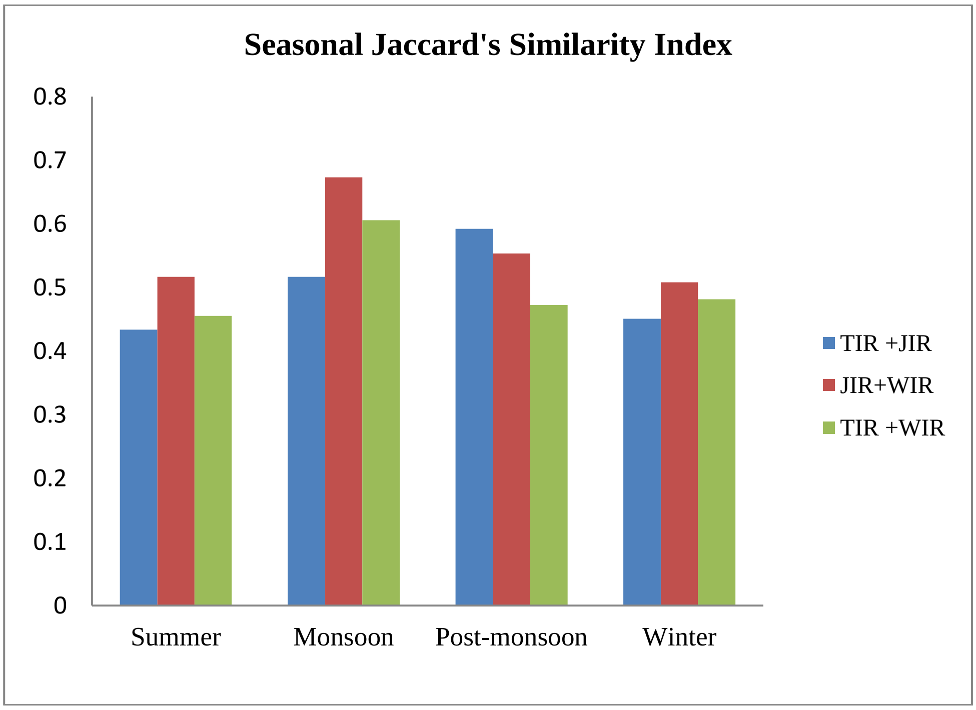


Figure 2.4: Annual mean Species Richness of different orders of insects at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

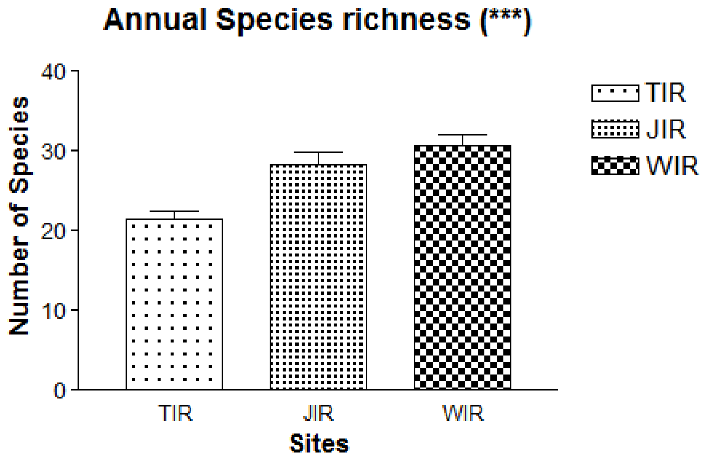


Figure 2.5: Seasonal mean Species Richness of different orders of insects at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

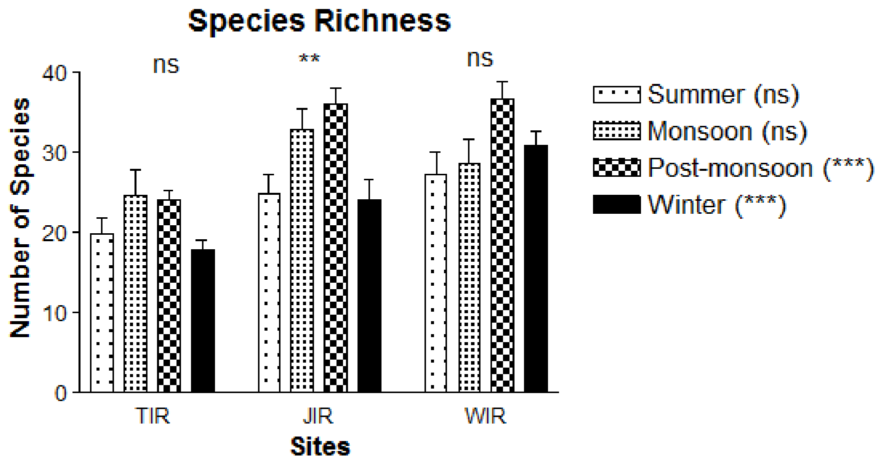
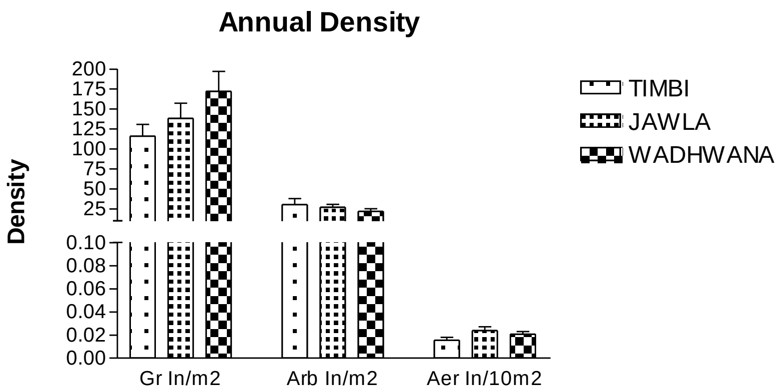


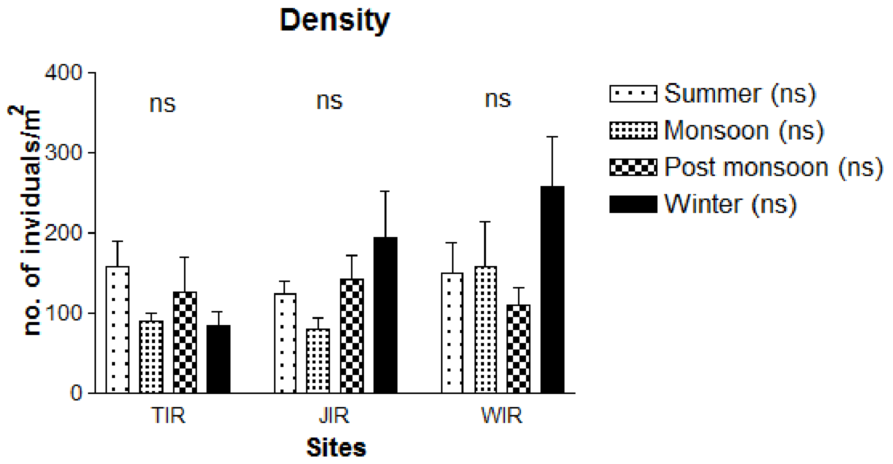
Figure 2.6: Annual mean Density of different orders of insects at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



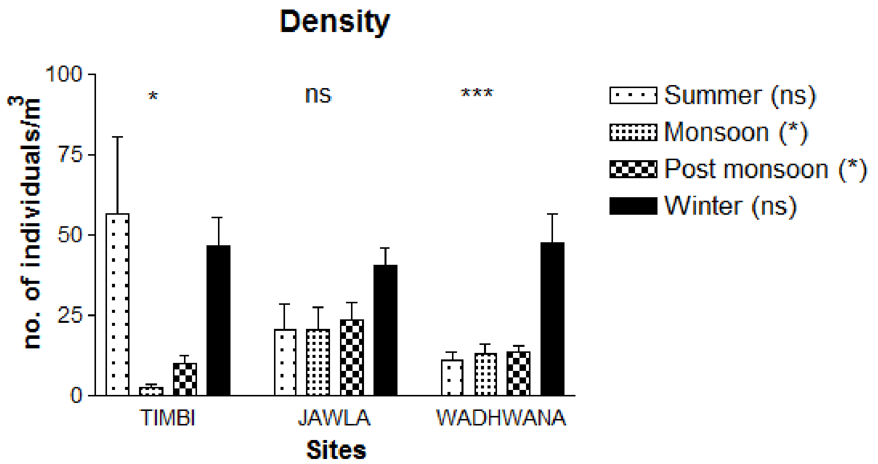
Gr In -Ground Insects,
Arb In -Arboreal Insects,
Aer In - Aerial Insects

For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

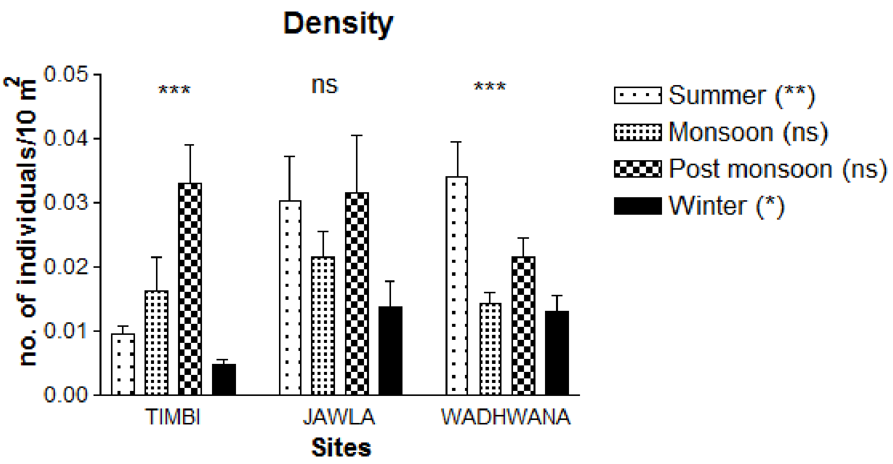
Figure 2.7: Seasonal mean Density of different orders of insects at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



(a) Ground Insects



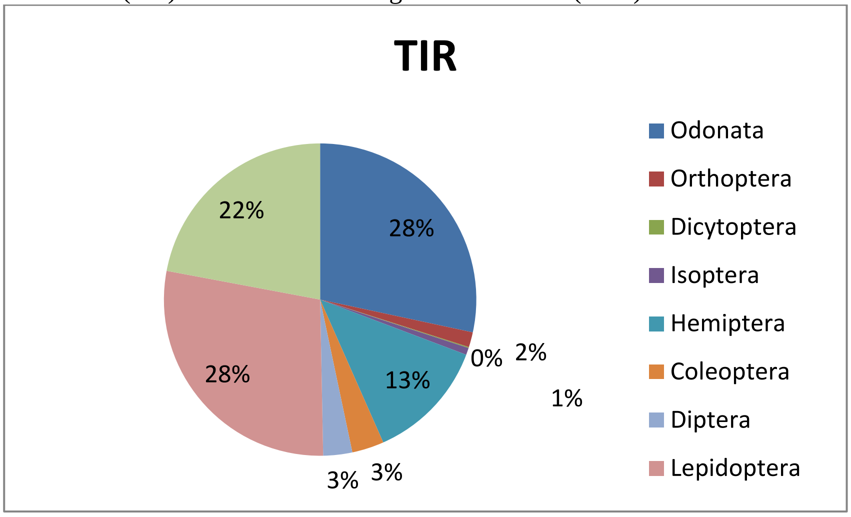
(b) Arboreal Insects

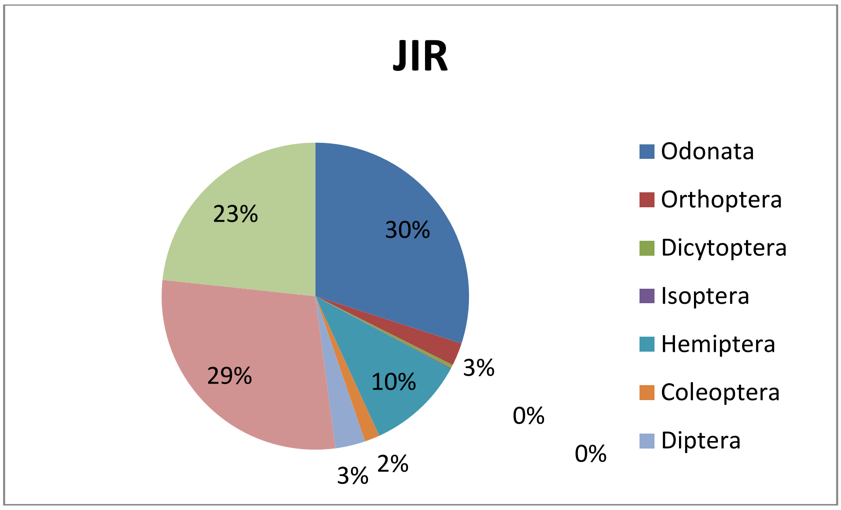


(c) Aerial Insects

For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

Figure 2.8: Annual Percentage Occurrence of nine insect orders at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)





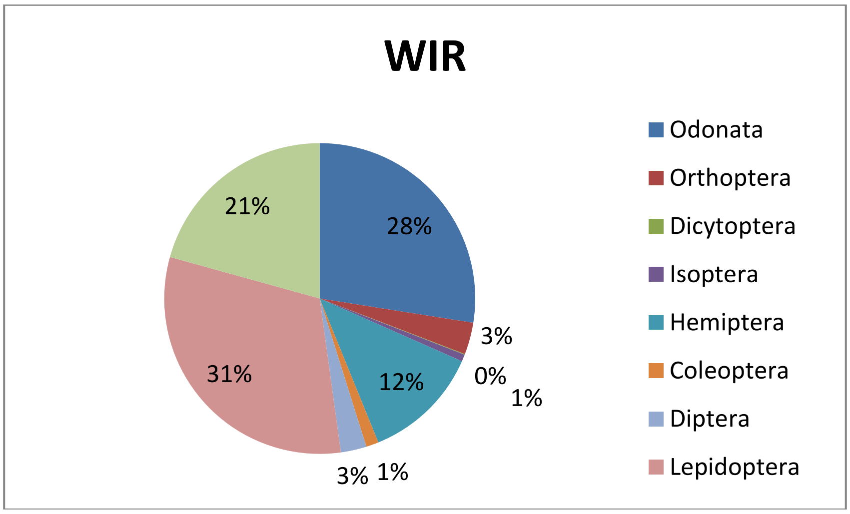


Figure 2.9: Seasonal variation in the Percentage occurrence of nine insect orders at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

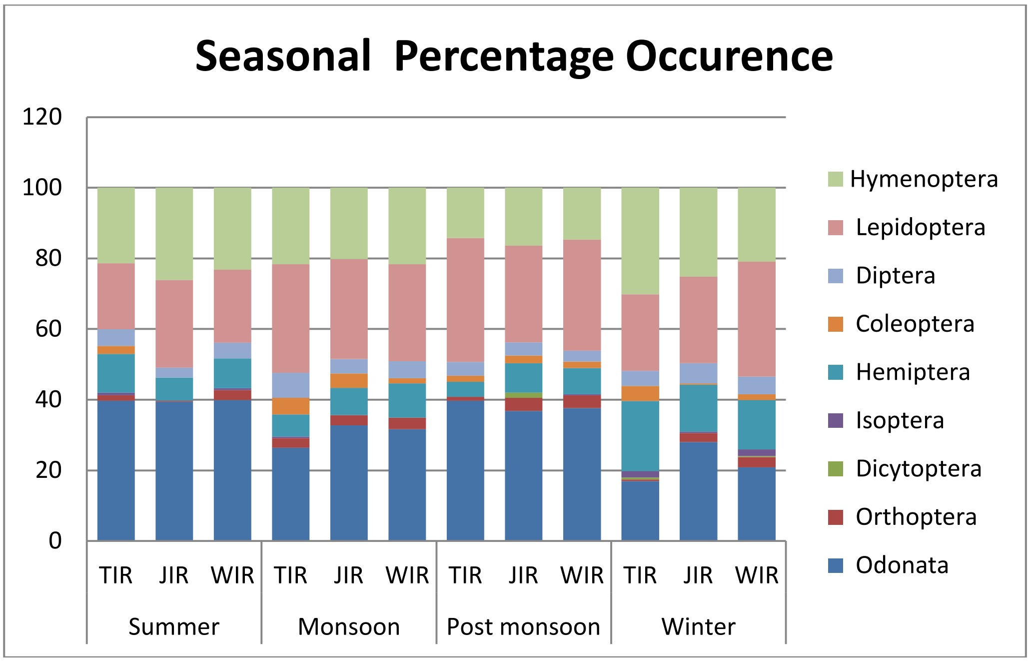


PLATE 7: INSECTS BELONGING TO DIFFERENT ORDERS

Piokilocercus pictus (Painted Grasshopper)

Gryllotalpa africana (Mole Cricket)

Txyallis turrita (Short horned Grasshopper)

Calliphora vomitaria (Blue bottle fly)

Myrabris sp (Click Beetle).

Utethesia pulchella (Tiger Moth)

Discussion

In the present study good insect diversity was recorded around three reservoirs. As is true for the Class Insecta that it can survive in a wide range of habitat conditions (Dana and Ross, 2004), the present work proves that the scrublands around wetlands in the semi arid zone of Gujarat, India are also the habitats used by various species of insects. Climate along with the vegetation and the interactions between the two, that varies spatially as well as temporally influence the distribution, abundance and richness of insect species significantly (Wolda, 1978; Marinoni and Ganho, 2003; Kittelson, 2004; Torres and Madi-Ravazzi, 2006; Silva *et al.,* 2011). In the tropical areas these changes are related to the changes from dry season to wet season (Wolda and Fisk, 1981). However, there are insects that are not equally affected by the changing climatic conditions and hence show no response to the variations especially in temperature and precipitation (Anu *et al*., 2009).These variations are reflected in difference in the numbers of species belonging to each insect order, may that be the major orders like Odonata, Hemiptera, Lepidoptera and Hymenoptera or minor orders like Orthoptera, Dicytoptera, Isoptera, Coleoptera and Diptera. Several studies report Lepidoptera, Hymenoptera and Odonata to be the dominant orders among all the insect groups (Ragaei and Allam, 1997; Gordan and Cobblah, 2000; Silva *et al*., 2011) with orders Odonata and Lepidoptera being the most conspicuous. Though, these major groups are useful in monitoring the changes in the habitat (Ragaei and Allam, 1997) the minor groups add to density and diversity to some extent and cannot be ignored.

As study was conducted in morning hours, the high number of Lepidopterans encountered in the present study includes very few moth species. If the study is extended to nocturnal species, it will add to the numbers of moths in the area increasing the Lepidopteran diversity. Among various insect fauna, especially the butterflies have been considered as useful ecological indicators (Gordon and Cobblah, 2000). Though the butterflies around wetlands have been documented at few instances, their presence around the water bodies is well noticed (Dana and Ross, 2004; Tiple and Khurad, 2009; Patil, 2011) and large varieties of these were observed in the present study too. Few moths observed belonged basically to four families. Of these, Tiger moth (*Utetheisa pulchella)* and Nine spotted Moth (*Syntomis phegea*) belonging to Arctiidae were the most common. These species are known to feed on host plants with poisonous chemicals in their larval stages and retain them in their adult lives which help them in defense against predators. They prefer drier areas and live mostly on the shrubs and trees in the open areas. This type of habitat is created around the reservoirs once the rain stops where the tiger moth was the most common. Noctuidae the family consisting of the economically harmful moths like Castor Semi-looper (*Achaea janata),* Cotton bollworm *(Helicoverpa armigera)* and Tobacco cutworm *(Spodoptera litura)* was observed around the reservoirs with all three species observed at TIR and WIR while the latter one absent at JIR. The larvae of all these moths are agricultural pest and hence the adults may be observed around the irrigation reservoirs. Other families present include Pyralidae that consist of wax moth represented by *Achroia sp.* at WIR and *Galleria sp.* at TIR. As the name suggests these species basically feed on the wax produced by the honey bees. As honeycombs are not present in the immediate surroundings of both the reservoir, these were probably observed during their exploratory tours. The Green hawk moth (*Pergesa acteus*) of family Sphingidae present only at WIR is a specific feeder. Its larva feeds only on soft leaves of particular plants while the adults are nectar feeders. This species was encountered once only hence rare in the area.

Another prominent insect order around the reservoirs, Odonata, includes Dragonflies and Damselflies (Chapter 3). As these are known to colonize around the water bodies their presence is indisputable. They are the bio-indicators aiding to monitor the alterations or changes in the aquatic habitats and have also been used as the indicator for wetland restoration (Kadoya and Washitani, 2007; Domsic, 2009) and conservation (Bried, 2005; Bried *et al.,* 2007, Clausnitzer, 2003; Davis *et al*., 1987). Other major groups represented around the three reservoirs, Hymenoptera and Hemiptera are interdependent as the most dominant species of both the orders show mutualism. Because of this relationship the presence of one enhances the chances of the presence of the other and *vice - a - versa* (Buckley, 1987; Morale and Beal, 2006, Chapters 4 and 6). The first order Hymenoptera that includes ants, bees and wasps get good habitat in the soil as well as on the bushes present on the earthen dam. The Solitary bees of this order are attracted to the plants present while the colonial honey bees build comb in the close vicinity, especially near WIR. However, ants that form the mutual relationship with treehoppers of order Hemiptera also form colonies on the earthen dam and frequent bushes where treehoppers are present. This increases the density and diversity of hemipterans too. Aphids, terrestrial bugs and water bugs also add to hemipteran density and diversity.

Among the five minor orders, Orthoptera was represented by four families Tettigonidae, Gryllidae, Gryllotalpidae and Acrididae. Of these first three belong to suborders Ensifera while the last to suborder Caelifera. The differential presence of these families *i.e.* family Tettigonidae and Acrididae common around all the reservoirs while the family Gryllidae at WIR and JIR and Gryllotalpidae at WIR only indicate the occurrence of species as generalist or specialist species as described by Teer (1995). The most common species of order Orthoptera the Short horned Grasshopper (*Txyalis turrita*) belonging to family Acrididae is known to inhabit the aquatic vegetation and hence was found around the wetlands. However, the presence of Painted Grasshopper (*Poikilocercus pictus*) and an unidentified species of Ground Grasshopper at all the three reservoirs indicates their wide tolerance. *Poikilocercus pictus* is known to prefer *Calotorpis sp.* (Rai *et al.,* 2011) which is very common around the three reservoirs. Ground Grasshopper is the species normally found on the ground, jumping from one place to other. These two were also the common orthopterans as they could get large variety of food in the bushes present around the reservoir. They easily camouflage due to their colour resembling the soil of the earthen dam which save them from being predated.

When the weather conditions are favourable, usually during post-monsoon, Field Crickets (*Gryllus campestris*) of the family Gryllidae were found at the reservoirs with agricultural matrix, JIR and WIR. They are not able to withstand the cold winters and hence are known to die with the onset of winter (Kenyeres, 2006). Field Crickets are more active during August to October (Kenyeres, 2006) which is the period of post-monsoon in India when weather is moderate in semi arid zone of Gujarat. Mole Cricket (*Gryllotalpa africana*) of family Gryllotalpidae was observed only once when it was trying to bore into the wet edges of WIR. It is known to be most active in summer (De Graff *et al.*, 2004) and in present study too it was observed in the same season. *Neoconocephalus ensiger* and *Microcentrum rhombifolium,* the long horned Grasshoppers belonging to family Tettigonidae were observed just once during monsoon. These are known to be most active during July- September period in the Indian climatic conditions which is the time when these were observed again around WIR. These grasshoppers are good mimics and camouflage very well with the habitat they live in. The fewer encounters of these two species can be due to their camouflaging ability or the lack of food for these voracious feeders.

The next minor order Dicytoptera that includes Cockroaches and Mantids was represented by a single species in the area. Cockroaches the household pests were completely absent. However, Mantids belonging to family Mantidae were represented occasionally by single species *Mantis religosa* also called Praying Mantis around all three reservoirs. For this predatory species preying on large variety of insects and residing on the surfaces where it can camouflage itself the preferred habitat was available only during monsoon.

Isoptera, the termites represented by a single species of genus *Rhinotermes* belonging to family Rhinotermitidae is a social insect basically living in big colonies of a Queen, a King, the Soldiers and the Workers. This species contributed greatly to the density of ground species. They were observed to build the soil nest on the edges of the earthen dam in different seasons at different reservoirs and were observed only once at JIR. High humidity with increase in the soil moisture is the main factor influencing the termite population (Pearce, 1997). Of the three reservoirs two are inundated with Narmada increasing their hydro period. This may have influenced the humidity and moisture in the soil. Termites inhabit soils with higher moisture contents compared to the dry soils. Hence, probably the absence of termites at JIR whose soil mainly depends on rains for the moisture. Soil characteristics in the area need to be investigated.

Coleopterans are weak fliers and most of the species are either ground dwellers or the plant sap suckers residing on the bushes. Three families of this order Coccinellidae, Dermestidae and Meloidae represented by single species each were present around all the three reservoirs. *Coccinella septempunctata* – the Lady bird Beetle (Family: Coccinellidae) is a bio-control agent reducing the pest in the agricultural fields *(*De Clerck-Floate and Carcamo, 2011). Their adults as well as larvae feed on aphids and jassids and hence reduce the damage caused by this pest. Though reported around all reservoirs, it was rarely observed as it could get better feeding options in the agricultural fields in the surrounding of the reservoirs. Family Dermestidae of carpet beetles again represented by single species *Attagenus sp.* is a household pest. Its presence around the reservoirs is surprising but may be attributed to the occasional presence of the dead animal skin in the area which could have attracted them. Meloidae the third family, again represented by a single species *Mylabris sp*. – the Blister beetle are the species known to secrete a fluid that causes blisters on the skin. Their larvae are insectivorous while the adults feed on the flowers and leaves. Both these food types are easily available in the vicinity of the three reservoirs surveyed and hence these were present at all three reservoirs.

Family Carabidae of order Coleoptera was the family that was also represented at the three reservoirs but with one species *Scaritus subterraneus* common at all reservoirs while another unidentified species of *Scaritus sp.* and *Anthia sexguttata* around TIR only. Carabids are the predacious ground beetles. *Scaritus subterraneus* is one of the common species found in wide range of environments and was found to be the most common species around the reservoirs. This species could be one of the generalist species. Curculionidae another family of Coleoptera includes True weevils that are called as the Snout beetles. These are basically host specific plant feeders that bore inside the food sources, may that be food grains (stored grain pests) or the stem of the bushes (the phytophagous species), and lay eggs destroying the crop completely. These are also known to destroy non-agricultural plants. Further, Buprestids the wood boring metallic beetles that feed by boring the stem of the plants were observed on the stems of *Acacia sp.*

Order Diptera one more minor order of the study includes flies that feed basically on the plant and animal exudates. This order is important for the humans as many flies are pests of agricultural plants, while others transmit diseases to humans and domestic animals while a few are beneficial as they help in decomposition of organic matter. Most of the dipterans are found all round the year while only few are seasonal (Parikh *et al*., 2008). *Chironomous* is one of the well known genus of Diptera due to their ability to survive in anoxic conditions. The larvae of this species are important indicators of pollution in water. The three reservoirs surveyed are not polluted hence the appearance of this species may be accidental or exploratory during which they could not find suitable polluted habitat to colonize.

Among all the flies that were recorded in the present study *Musca domestica* was the only species that was observed several times while rest all were rarely observed. *Musca domestica* is a generalist dipteran species found everywhere in India. Another rare species *Calliphora vomitaria* (Blue bottle fly) showed varied presence at the three reservoirs indicating the differences in micro-habitats while *Sarcophaga* sp. (Flesh fly) was observed frequently. *Calliphora vomitaria* and *Sarcophaga sp*. are saprophytic in nature or feed on carrion or decaying matter (Parikh *et al*., 2008). These two species were more common at JIR where the dead cattle are dumped at the side of the reservoir and hence could have attracted these flies. At WIR both species were observed thrice during the study period while at TIR only *Sacrophaga* sp. was present and the other species was totally absent probably due to the unavailability of the favourable conditions. Similarly the species that could not find favourable habitats at the three reservoirs and were encountered only once are two tabanid flies at JIR and one at TIR, *Anopheles sp.* of Family Culicidae around all three reservoirs and *Drosophila melanogaster* of Drosophilidae at TIR and JIR. Tabanids- the horse flies have been encountered near the water surface where they lay eggs as their larvae are aquatic. The appearance of Drosophila, fruit flies known to feed on the rotting fruits and vegetables, may also be accidental. At the three reservoirs they were observed in monsoon when the area is in shamble attracting this species.

Jaccard's Similarity Index (J)

Annual Jaccard's similarity index is always high compared to the seasonal as the species present may move up to certain distance over time. The distance between the three reservoirs surveyed is about 25-50 Kms. Hence, the movements of insects due to natural conditions or human involvement cannot be ruled out. However, no definite outcome was evident regarding the similarity of the total insect species at the three reservoirs as the highest annual Jaccard's similarity index (68%) was found between TIR and JIR with lower seasonal similarity index. This is reflected as less than 50% similar species between the three reservoirs in summer and winter when the atmosphere is hostile due to extreme temperatures. However, in monsoon when the environmental factors are favourable the similarity was comparatively higher. This indicates that when macroclimatic conditions in the area were moderate various insect species were distributed in wider area. As the conditions become hostile they become restricted to the microclimatic conditions of the reservoirs decreasing similarity indices. Monsoon is the season when productivity increases with favourable atmospheric conditions when many insects come out of aestivation. More the species more are the chances of them being common at two nearby places. During summer and winter similarity is low due to hostile environmental conditions when species may not explore the surroundings for establishment.

Species Richness

Species richness provides an extremely useful measurement of diversity where a complete catalogue of species in the community is obtained (Magurran, 1988). Hence, finding out species richness is of utmost importance in the Ecological studies of any ecosystem. The species richness around the three reservoirs clearly indicated that the number of species present in a habitat greatly depends on its microclimate. Larger area supports more species (Rosenzweig, 1995; Oertli et al., 2002). This is apparent at WIR which is largest of the three with varied microhabitats and supporting highest species richness and vice versa at TIR which is the smallest amongst the three. Another factor influencing the species richness is the level of human pressures faced. WIR is undisturbed habitat hence the number of species present therein may be positively influenced whereas TIR faces moderate human disturbances due to its domestic usage and pressures of urban expansion. The human movements may affect the species present therein. At JIR the reservoir with moderate size and low human impact moderate species richness was recorded.

Rainfall acts as the precursor for the increase in insect density and diversity (Levings and Windsor, 1982; 1985; Lowman, 1982; Wolda and Denlinger, 1984; Wolda, 1988; Boinski and Fowler, 1989; Frith and Frith, 1990; Sabu *et al.*, 2008; Anu *et al*., 2009). This is reflected at the three habitats surveyed where maximum species were observed during monsoon at TIR and in post-monsoon at JIR and WIR. The first is the wet season of the year followed by the second with favourable environmental conditions for the insects to grow. However, the rainfall is lower in the city (TIR is present nearer to the city) while higher in the areas away from the city (JIR and WIR located far from city limits) (Table B). Ahmed *et al*. (2004) also found highest insect population during July-August at Faisalabad in Pakistan when the relative humidity and rainfall were highest favouring the insect population. Silva *et al.,* (2011) in their study in Brazil (Southern Tropics) also reported highest insect abundance during September - November period. In the present study of subtropics the highest abundance as well as density was observed during the same months which are considered as the Indian post-monsoon.

In the following season, the winter, cool climatic conditions prevented proliferation of insets when many of them are expected to enter into diapauses. However, as the temperature starts increasing leading to summer, some species of insect proliferate for short period but again enter dormancy as summer sets in. A sharp reduction in abundance occurring during the dry season is reported to be restricted to tropical habitats where there is severe drying (Janzen and Schoener, 1968; Janzen, 1973a; 1973b; Wolda, 1977; 1978). Hence, in the typical tropical conditions of India when vegetation dries up in summer the species richness is low due to the stress caused by the shortage of food (Janzen, 1973b) and the unfavourable conditions. During this season the temperature is high producing dryness the characteristic unsuitable for growth and development of insects. This has probably evolved into a series of strategies and adaptations, such as dormancy, diapause and migration of insects (Janzen and Schoener, 1968; Denlinger, 1986; Wolda, 1988; Braithwaite, 1991).

In tropics, on an average the activity patterns of the insects are longer and many species are active all round the year and hence major seasonal peaks are absent (Wolda, 1988, Silva *et al*., 2011). However, the seasonal gradient in the tropics is better defined in the areas with distinct wet and dry seasons (Silva *et al*., 2011). The reservoirs in the present study selected are located in subtropics where distinct wet season is observed only in July –August when species richness is observed to be highest while in post-monsoon no major differences were observed. The first rains of the season influence the insect activities with a sudden increase in their population (Wolda, 1988). The rains lead to growth of fresh leaves that influence insect population by increasing food availability. Newer leaves are softer and contain lower toxin levels with higher nutrient contents (Feeny, 1970). This availability of resources plays an important role in the seasonal patterns of insects (Wolda, 1978; 1988) increasing their numbers. Families influencing the species richness in monsoon include Lepidoptera and Odonata. Odonata has two peaks in a year; an early summer peak and a post-monsoon peak (Patil, 2011). These seasons are called as their flight periods hence during early summer and post-monsoon the species richness is influenced by higher number of species belonging to this order while during monsoon this increase is due to the presence of all the orders without dominance of any particular one.

The overall low species richness at TIR in summer compared to JIR and WIR could be due to comparatively higher temperature at the wetland under urban influence which is likely to affect the Odonates -the main species richness contributing group. However, Hymenoptera was also one of the prominent order contributing to the summer species richness as the ants are more active in the dry season as compared to the wet period of the year. Higher species richness at JIR compared to WIR during monsoon is due to the difference in the status of vegetation at the two reservoirs. At JIR, reeds are present towards the dam side providing resting points to Odonates and butterflies whereas at WIR such reeds were absent towards the dam side. However, both Odonata and Lepidoptera contributed to higher species richness. Post-monsoon showed nearly same species richness at JIR and WIR suggesting that both the reservoirs retain same characteristics except rains. In winter though the species richness was low at JIR it was mainly contributed by Hemipterans while at TIR this was contributed by Hymenopterans as well. Hymenopterans explore both ground and arboreal niches whereas Hemipterans prefer bushes a clear difference in the available habitats leading to differences in species present. In winter, at the third reservoir WIR, the species richness was mainly contributed by Lepidopterans (Chapter 5) in addition to the above mentioned two orders. Hence in the three habitats surveyed differences in the insect diversity was noted mainly due to differences in vegetation pattern. This pattern is influenced by human activities also as is noted for TIR where lowest species richness was recorded during all the seasons of the year.

Density

The ability to colonize multiple niches is an indication of the biological success of many species, especially those that are ecologically related (Putman, 1995; Begon, 1996; Torres and Madi- Ravazzi, 2006). Thus, the presence or absence of a species in an ecological niche, and its abundance in that area is an indication of both biological and ecological diversity of that ecosystem (Guruprasad *et al.,* 2010). Multiple processes, biotic and abiotic, resulted due to the seasonal variations along with the topography are responsible for this phenomenon (Pinheiro *et al.,* 2002).

The density of the insects, evaluated by three different methods depending on the habitat they utilize, showed seasonal variations. The comparison between the three sampling technique cannot be made. However, among the three sampling technique maximum density was recorded in the Quadrat sampling used for ground insects like ants which are social insects found in larger numbers. In the study by Gordan and Cobblah (2000) in the Muni-Pomdez Ramsar site, the majority of the insects found were the Hymenopterans – mostly the ants with beetles and termites. The density of Ants and Termites - the Social insects is always higher. Bush count method used for the arboreal insects basically included the Hemipterans along with ants that are known to have mutualistic relationship with the treehoppers the key species of the order Hemiptera. The density by this method was moderate as with increase in the surface area the unit of measurement becomes small. The third method Point count method estimated the number of flying insects which principally consists of Lepidopterans and Odonates along with the bees belonging to order Hymenoptera. As flying insects are mobile and were calculated per minute, their number was low compared to ground and arboreal groups.

Maximum density of ground insects was noted at WIR as the area is least disturbed and hydro-period is extended in the region due to Narmada inundation. Hence there are more chances for the nest building by the social insects like Termites which require moisture in the soil. This is reflected at JIR which is not inundated with Narmada where termites were observed only once. TIR is the most disturbed reservoir hence supports low density of this group. However, the density contributed by ground dwelling ants at all the three reservoirs was quite satisfactory indicating that the scrublands around the irrigation reservoirs in the semi arid zone of Gujarat are good habitats for ant diversity.

Among the arboreal insects, highest density encountered at TIR can be due to the higher number of treehoppers and arboreal ants. In the bush count method, the height of the bushes influences the density. Larger the bush larger is the area available for the insects to inhabit while smaller the size of the bush lesser is the area available. At WIR, the bushes on the earthen dam were smaller in size and were removed annually under management practices resulting in overall low surface area. At TIR, the bushes are taller with higher density influencing the density of arboreal insects positively. The earthen dam at JIR is frequently used for transportation that disturbs the vegetation. Hence, moderate density of insects.

Density of aerial insect measured by Point count sampling was observed to be maximum at JIR. The habitat at JIR is more suitable for the flying insects where they get more space for hiding as well as perching in and on the tall vegetation as compared to other two reservoirs. Additionally trees present in the center of the earthen dam near the temple also provide perching and resting spots for the flying insects. However, the insects present away from the trees were frequently disturbed by the movement of the bullock cart. WIR also had moderate density of the flying insects which was mainly contributed by the Lepidoptera and Odonata. As said earlier, the lower density of flying insects at TIR may be attributed to the disturbances on the earthen dam.

Seasonal Density

As said earlier the seasonal variation in the abundance of tropical insects is a common phenomenon (Wolda, 1988; Pinheiro *et al*., 2002). The seasonality in insect populations has been expected to be consistent from year to year, but vary in amplitude with environmental factors such as temperature and rainfall (Lowman, 1982). Although the macroclimatic and microclimatic changes trigger seasonal activity of insects in tropical regions (Tauber and Tauber, 1976; Denlinger, 1986; Wolda, 1988; Basset, 1991; Tanaka, 2000; Kai and Corlet, 2002; Pinheiro *et al*., 2002; Nahrung and Allen, 2004; Nakamura and Numata, 2006; Anu, 2006; Danks, 2006; Vineesh, 2007), rain plays the major role. Though, onset of rains increases the insect density and diversity, Robinson and Robinson (1970), Boinski and Fowler (1989) and Pinheiro *et al.* (2002) have reported a decline in the numbers of several groups of insects due to maximum stress and minimum amount of food available during the wet mid-season, sometimes even lower than the dry summer.

On the contrary, in Jamaica a decrease in rainfall has been reported to increase the number and alter the composition of populations especially of adult Hemipteran species (Rees, 1983). Similar conditions were found in present study when the species richness was high during peak rainy seasons while the density was low and *vice versa* during summer.

Ground Insects – In summer the density of this group was highest at TIR as ants emerge from their burrows to collect food for the upcoming monsoon. Contrasting to this, the highest density of ground insects was found during winter at JIR and WIR the two comparatively undisturbed reservoirs. Ant colonies were more common during winter at these two reservoirs and hence their higher density. Bruhl *et al.* (1999) and Anu *et al.* (2009) also reported peak abundance of Formicidae- ants during the dry seasons as the wet seasons make the foraging difficult. Hence, lowest density of this group was observed during monsoon at TIR and JIR and also during post-monsoon at JIR. During these seasons the earthen dam at JIR is completely covered with bushes that can maintain the moisture preventing ants to construct their colonies. Further, the heavy monsoon during the study years might have washed away the ant colonies leading to their lower density. Among the three reservoirs the highest density was recorded at WIR where level of disturbance is low. The soil characteristics are very essential to estimate the reasons for the increase or decrease of the soil dwelling insect populations. Hence as said earlier the study of soil characteristic may help in the prediction of the fluctuating populations of the ants.

Arboreal Insects – The lower density of arboreal insects during monsoon and post-monsoon at TIR may be attributed to the absence of Aphids and the low density of the ants and Treehoppers due to the disturbance caused by the rains. *Camponotus compressus, Oxyrhachis tarandus* along with *Aphis gossypii* contributed to the highest density of arboreal insects during summer at TIR. However, their highest density observed during winter at JIR and WIR may be accredited to the dry conditions. Winter is not severe in the area with temperature fluctuating between 10º to 15ºC at midnight to 28º to 30ºC in the afternoons. However, the higher density may be accredited to the presence of the Ants, Treehoppers, Aphids as well as Milkweed bugs in large numbers compared to the other seasons of the year. As said earlier the lower densities at WIR were due to low and scattered bushes compared to JIR where the earthen dam is completely covered by the bushes.

Aerial Insects - The unfavourable environmental conditions like fluctuation in temperatures in summer and winter of sub tropics might have affected the flying insect populations. Several insects are known to hibernate and aestivate during unfavourable conditions decreasing the overall density. The density of the flying insects mainly contributed by Odonates and Lepidopterans, may be correlated to their flight period associated with the availability of perching posts (Odonates) and food plants (Lepidopterans). The differences are noted with reference to reeds available near the dam and also bushes covering the earthen dam (Chapters 3 and 5).

Percentage occurrence

Percentage occurrence strongly depends upon the number of species in different orders at a particular time influencing all the orders considered.

Annual

The dominance of three major orders namely Odonata, Lepidoptera and Hymenoptera was observed around the reservoirs surveyed. Odonata depend on the reservoirs for egg laying while Lepidopterans are omnipresent hence their higher percentage occurrence. Hymenoptera also had higher percentage occurrence due to the ants that were present almost all throughout the year. Hemiptera was the order with moderate percentage occurrence due to low number of species. All other orders had low percentage occurrence as they were represented by few species that also appeared only during certain season of the year. Because of the absence of grasslands around the reservoirs studied the percentage occurrence of Orthopterans which prefer grasses was low in the study area. Dicytoptera and Isoptera represented by a single species each resulted in their low occurrence. Coleoptera, the largest order of the Class Insecta preferring forested tracks had low percentage occurrence in the dry open scrubland. Similarly Diptera also could not find its basic feeding niche and hence was uncommon around the reservoirs.

Among the three reservoirs, reeds present near earthen dam at JIR provided perching post to Odonates increasing their percentage occurrence. The influence of size of the habitat is seen in Lepidopteran percentage occurrence at WIR which is having varied microhabitats while the influence of solitude is noted at JIR with higher Hymenopteran percentage occurrence. Similarly Hemiptera could find better habitats at TIR and WIR that resulted in its moderate percentage occurrence. Among the orders that occurred with low percentage occurrence around reservoirs, Orthoptera found more suitable habitats around WIR where some grasses are present on the earthen dam. However, a single species of Dicytoptera, *Mantis religosa* probably trying to inhabit the area was noted thrice at JIR and once each at TIR and WIR which led to their lower percentage. Its past status in the area is not known. Contrarily, Isoptera was observed frequently at TIR and WIR while rarely at JIR indicating differences in the microhabitat characteristics of the area. Such opposing trend is also noted for Coleoptera with 11 species encountered at TIR and Diptera with 8 species at JIR indicating differences in the microclimate depending upon various environmental and human induced features.

Seasonal Percentage Occurrence

Summer and Post-monsoon being the flight period of Odonates, their seasonal percentage occurrence was high during this period. Similarly, the high percentage occurrence of Lepidoptera during monsoon and post-monsoon could be attributed for this period being the most favourable period for the butterflies (Kunte, 1997). However, at

WIR their percentage occurrence was high during winter due to availability of varied microhabitats at the larger reservoir supporting this group. Kunte (1997) observed one peak in the butterfly population during early winter which may be considered as the post-monsoon in the present study. In summer, compared to other two reservoirs, higher percentage of Lepidoptera at JIR was due to the presence of species able to survive the dry and harsh summer conditions as is also reported by De Vries (1987).

High percentage occurrence for Hymenoptera was also observed during winter for TIR and JIR due to the presence of good vegetation on the earthen dam. However, this group had comparatively lowest percentage during post-monsoon when the season is favourable for other groups of insects too decreasing their percentage occurrence. These results are contrary to the results of the study conducted by Silva *et al*., (2011) in Brazil where the swarming hymenopterans were observed at the onset of the monsoon. As the reservoirs were visited once in 15 days no such swarming could be documented but it is likely to occur. Majority of Hymenoperans being pollinators, parasitoids and/or predators, get ample food during monsoon (Morais and Diniz, 2004) increasing their percentage occurrence.

Lower percentage occurrence of Hemiptera at JIR in all the seasons is due the higher occurrence of Odonata, Lepidoptera and Hymenoptera which mathematically lowers the percentage occurrence of Hemiptera when comparison is made. However, their maximum percentage occurrence was observed in winter when Aphids and white flies along with treehoppers were more prevalent.

The grasses present in monsoon and post-monsoon provided good habitat to Orthoptera - the grasshoppers and Crickets increasing their percentage occurrence. Single Dicytopteran encountered was almost absent in three seasons at all the three reservoirs due to lack of suitable habitat for their survival. Isoptera, the termites, were also observed only once or twice around JIR while frequently at the other two reservoirs hence had lower percentage occurrence. Coleopterans, the beetles, also do not prefer this type of habitat hence were nearly absent. However, the later exhibited highest occurrence in monsoon which is considered to be one of the favourable season for insects in general (Dowd and Nelsen, 1994) when the food is available in plenty for the herbivorous coleopterans (Silva *et al*., 2011). In humid tropical regions, the seasonality of Coleoptera has also been observed, with higher abundance in the wet period (Noriega *et al.* 2007). During winter though more species were present at TIR, their percentage occurrence was higher at WIR mainly due to presence of the Ground beetles. Contrasting to the results of the dominance of Diptera in dry deciduous forest during summer (Parikh *et al*., 2008), here in the scrub around wetland, they were found to be more common during monsoon. As Diptera prefers very heterogeneous habitats and have varied feeding habits, difference in their peak is natural (Silva *et al.,* 2011). The dipteran larvae develop in varied aquatic habitats while their adults that feed on wide substrates prefer terrestrial habitats (Teskey, 1991; Guimarães and Amorin, 2006).

Although Climate plays a major role in the seasonality of insects, it solely can't regulate the insect populations. Other factors like interspecific competition, predation, parasitism, distribution of the food resources at a particular time of the year, *etc.* also influence the patterns of distribution and abundance of insects (Silva *et al*., 2011). Another factor that regulates the insect population is predation by insectivorous birds. When birds breed they require more food to support themselves and also to feed the young which negatively influence the insect population. Hence, the breeding of many insectivorous and gramnivorous species depends on the availability of protein rich insect food and hence breeding of birds coincides with the onset of the rainy season when ample food is available (Dingle and Khamala, 1972).

In addition, the conditions of microhabitats available is also important as is reflected in the present study where the scrubland around three irrigation reservoirs in the semi arid zone of Gujarat, India; at a distance of about 25 to 50 Kms. show seasonal difference as well as site specific difference in species richness, density and abundance of insect diversity.

ODONATE DIVERSITY AROUND WETLANDS

Introduction

Odonata is the order consisting of the Dragonflies (Anisoptera) and Damselflies (Zygoptera), which is a small but well-known order of insects with wide distribution. Adult dragonflies and damselflies are the most easily recognizable insect taxa (Maiolini and Carolli, 2009), due to their comparatively larger size amongst the insects, bright colours and diurnal nature with interesting behavioural patterns.

All the Odonates have aquatic nymphs that are active predators preying on almost any kind of ingestible organisms they can perceive. The adults are highly adapted for an active aerial life and most of their behaviour takes place on the wings. They are generalized, obligate carnivores (Corbet, 1962) predating on small insects predominantly during flight (Mitra, 2007). Anisopteran larvae leave the water shortly before dawn while the zygopteran larvae during the day (Miller, 2007). Their adult life is mainly composed of two behavioural patterns, Feeding and Reproduction. The first half after the emergence as adult is utilized for dispersal and feeding so that the young imago can develop into mature adults while the second half, after getting itself established in a habitat, is utilized mainly for the purpose of reproduction.

Odonata is a relatively well-known order of insects whose members breed in a wide variety of aquatic habitats. Some species are specialists that use discrete habitats and others are generalists that are able to survive in different types of environments (Cannings *et al.*, 2007). For several reasons, odonates are given priority in inventory of biodiversity of a habitat (Scudder, 1996). Unlike most invertebrates, they can be relatively easily identified, even in field in many cases. They are upper level predators in the invertebrate food chain and have often been identified as indicators of ecosystem health (Walker and Corbet, 1975; Carle, 1979; Takamura *et al*., 1991; Clark and Samways, 1996; Trevino, 1997; Corbet, 1999; Cannings *et al*., 2007). Many species are habitat specific, and their presence has been used to characterize health of wetlands of all sorts. Odonates are also considered among the most popular 'flagship' groups of insects (Oertli *et al*., 2002), and parallel the role for aquatic environments that the butterflies play for terrestrial ones (Hawking and New, 2002) and are well suited for long-term monitoring programs (Cannings *et al.,* 2007). Their amphibious life history, relatively short generation time, high trophic position, and diversity (Corbet, 1993; Clark and Samways, 1996) are the characteristics that make them indicator species useful in providing an early warning system for subtle (and not so subtle) shifts in water quality, biotic community composition, and trophic dynamics due to human activities in and around wetlands.

As Anisopteran species have excellent flying capacities, they are not expected to meet great difficulties in extending their range. However, Zygopterans are weak fliers and hence face greater difficulties in extending their range (Beukema, 2007). Compared to dragonflies, damselflies are adapted to a larger variety of habitats, indicating the greater ecological diversity of this taxon (Steytler and Samways, 1995).

Being primarily aquatic, their life history is closely linked to the specific aquatic habitats. It is possible to detect a community of this group around ponds or streams. The diversity of dragonfly species is considered as an emergent property of such ecological category (Begon *et al*., 1996; Perez *et al.,* 2007). However, the Odonates show low correlations with environmental variables in microhabitat scale; while, strong correlation at biotope scale, and hence are postulated as good indicators of particular habitats (Samways *et al*., 1996).

As their life cycle depends on the suitability of both aquatic and terrestrial habitats along with abundant and diversified prey (Maiolini and Carolli, 2009), the presence of the optimum conditions in the habitat regulate their population. Hence diversity of the local odonato-fauna is determined by the overall ecological quality of water bodies and related land-water ecotones (Chovanec and Waringer, 2001; Schindler *et al*., 2003; Chovanec *et al*., 2004; Smith *et al.,* 2006). In other words, they show strong relationship with the structure and ecological integrity of their habitats (Chovanec, 1994; Steytler and Samways, 1995; Sahlén and Ekestubbe, 2001; Hawking and New, 2002). They have been used as the bio-indicator of the wetland quality and are a flagship species for certain tourism attractions in Europe, Australia, USA and Japan (Clausnitzer and Jödicke, 2004). In Japan, Europe and South Africa, study of dragonflies have been recommended at many instances for the conservation of the ecosystem (Bried, 2005).

Studies on Odonata includes relationships with water quality (Azrina *et al.,* 2006), biotope quality (Clark and Samways, 1996; Clausnitzer, 2003) and general species richness (Sahlen and Ekestubbe, 2001; Briers and Biggs, 2003), and their use as indicators for wetland conservation (Bried *et al*., 2007), riparian management needs (Samways and Steytler, 1996), wetland buffer width requirements (Bried and Ervin, 2006) and shallow lake restoration (D'Amico *et al.,* 2004). As a group of species that are especially sensitive to changes in their habitat, Odonate populations can also be indicative of the richness of other invertebrates and macrophytes (Corbet, 1999; Bried and Ervin, 2005) and is also considered to act as umbrella species, facilitating the protection of habitat that is crucial for the survival of other species (Bried and Ervin, 2005). Dragonflies are known to be very sensitive to structural habitat quality and thus can provide a valuable tool to evaluate landscape degradation (Rith-Najarian, 1998; Sahlén, 1999; Clausnitzer, 2003). Considering these facts, in the present study around wetlands in semi arid zone of Central Gujarat, the Odonate fauna was documented.

Results

Most of the Odonates prefer environment near water bodies, hence good diversity and density of odonates were recorded in the present study conducted in the area surrounding three reservoirs in Central Gujarat.

Number of species (Table 3.1, Figure 3.1, Annexure 2)

Total 45 species of Odonates present around the three reservoirs included 18 species of 4 families (Coenagrionidae, Lestidae, Protoneuridae and Platycnemididae) of sub-order Zygoptera (Damselflies) and 27 species of 4 families (Aeshinidae, Gomphidae, Cordulegasteridae and Libellulidae) of sub-order Anisoptera (Dragonflies). Of the Zygopteran families, 3 families each were present at the three reservoirs, TIR, JIR and WIR represented by 12, 14 and 13 species respectively while of Anisopteran families, 23 species representing all 4 families were present at TIR while 23 species belonging to only 2 families were observed at JIR and 22 species belonging to 3 families at WIR.

Among the Zygopteran families, Coenagrionidae was the richest family with 9, 12 and 10 species recorded around TIR, JIR and WIR respectively. Lestidae was represented by only 2 species each at TIR and WIR while a single species at JIR. Protoneuridae was represented by a single species only at WIR. Platycnemididae was also represented by a single species at TIR and JIR. Sub-order Anisoptera had higher species richness than Zygoptera at all the three reservoirs. Libellulidae of this sub order was the richest Anisopteran family with 19 species each at TIR and WIR, and 21 species at JIR. Other Anisopteran families include Aeshnidae with a single species at TIR, Cordulegasteridae with a single species at both TIR and WIR and Gomphidae with 2 species at all the three reservoirs.

Abundance Rating (Table 3.2, Figure 3.2, Table 3.8)

Three species *Trithemis pallidinervis, Brachythemis contaminate* and *Crocothemis servilia* of family Libellulidae were abundant at WIR. Of these first two were common at TIR and last two at JIR. Five species were rated as Common at TIR and WIR each while 4 at JIR. Besides the above mentioned two species, common species at TIR include *Ischnura senegalensis, Ictinogomphus rapax and Pantala flavescens* which were also common at WIR. In addition two species *Diplacodes trivialis and Crocothemis* *erythraea* were common at WIR while frequent at the other two reservoirs. *Diplacodes lefebvrii and Rhyothemis variegate* were rated as common at JIR. Four species of Anisopterans were rated as frequent at TIR while 2 species each of Zygopterans and Anisopterans at WIR while JIR showed presence of 9 frequent species. These include *Bradinopyga geminate* at TIR and WIR, *Crocothemis servilia, Diplacodes trivialis and Crocothemis erythraea* at TIR while *Pseudagrion microcephalum, Onychargia sp.* and *Trithemis aurora* at WIR. The frequent species at JIR include two species of *Ischnura, I. aurora and I. senegalensis, Onychargia sp., Ceriagrion coromandelium, Pantala flavescens, Sympetrum vulgatum, Trithemis pallidinervis Diplacodes trivialis and Crocothemis erythraea.*

Ten, eight and eleven species were uncommon at TIR, JIR and WIR respectively. Rare species amounted to the largest number with 16 species at both TIR and JIR while 12 species at WIR. Species representing families Lestidae, Protoneuridae, Platycnemididae, Aeshnidae and Cordulegasteridae were observed once or twice and hence all were rated rare in addition to some species of family Coenagrionidae and Libellulidae.

Jaccard’s Similarity Index (J) (Table 3.3)

The **annual** Jaccard’s similarity index for odonates was maximum 0.71 for TIR and JIR while 0.63 and 0.64 for TIR and WIR and JIR and WIR respectively (Figure 3.3). The **seasonal** Jaccard’s similarity index (Figure 3.4) showed variations without any specific trend in all the seasons. The highest 0.68 similarity occurred between JIR and WIR during monsoon when the similarity between TIR and JIR was 0.52 and that for TIR and WIR 0.54. In post-monsoon, the highest similarity of 0.65 was observed between JIR and TIR while for TIR and WIR and JIR and WIR it was 0.49 and 0.59 respectively. The similarity in winter at the three reservoirs varied with 0.46, 0.47 and 0.56 for TIR and JIR, JIR and WIR and TIR and WIR respectively. In summer the similarity index between TIR and JIR was found to be 0.51 , JIR and WIR 0.59 and WIR and TIR 0.5.

Annual Mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) (Table 3.4, Figure 3.5)

Species Richness –The annual mean Species richness of Odonates was found to be highest 8.71 ± 0.64 species at JIR and lowest 6.09 ± 0.53 species at TIR. At WIR it was 8.44 ± 0.56 species with moderately significant differences among the three reservoirs ($p < 0.01$, $F_{(2, 125)}$ 6.48).

Density – The annual mean density of Odonates was found to be highest 0.61 ± 0.13 individuals/10m^2 /min at WIR while lowest 0.32 ± 0.1 individuals/10m^2/min at TIR. Density at JIR was moderate with 0.36 ± 0.08 individuals/10m^2/min. The differences among the three reservoirs were non-significant ($p > 0.05$, $F_{(2, 125)}$ 2.22).

Shannon Weiner Diversity Index (H') – The annual mean H' for Odonates was maximum 1.51 ± 0.08 at WIR while minimum 1.21 ± 0.09 at TIR. For JIR it was 1.46 ± 0.09. The differences among the three reservoirs showed significant differences ($p < 0.05$, $F_{(2, 125)}$ 3.37).

Evenness (E) – The mean annual evenness for Odonates was more or less same for TIR and WIR with 0.73 ± 0.05 and 0.72 ± 0.04 respectively while 0.68 ± 0.05 for JIR and hence differences among the three habitats were non-significant ($p > 0.05$, $F_{(2, 125)}$0.28).

Seasonal Variations in mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) (Table 3.5, Figure 3.6)

Species Richness

Around the three reservoirs same seasonal trend in the species richness of Odonates was observed with higher mean species richness during summer and post-monsoon and lowest in winter.

Seasonal variations around Each Reservoir

TIR- The mean species richness showed variation in different seasons of the year at TIR with highest 8.46 ± 1.12 species in post-monsoon which decreased to lowest 3 ± 0.39

species in winter. The mean seasonal species richness in summer was 7 ± 0.88 species while in monsoon it was 6.1 ± 1.07 species. The seasonal variations varied highly significantly ($p < 0.001$) with $F_{(3,41)}$ 7.03).

JIR – At JIR, the mean seasonal species richness of Odonates was 9 ± 0.85 species in summer which increased in monsoon to 9.5 ± 0.91 species and reached to maximum 11.57 ± 1.11 species during post-monsoon and was lowest 6 ± 1.45 in winter. The seasonal differences showed significant variations ($p < 0.05$, $F_{(3,34)}$ 3.84).

WIR – The mean seasonal species richness at WIR oscillated over the year with 9.58 ± 1.05 species in summer which decreased in monsoon to 7.91 ± 0.95 species and increased to highest 10.9 ± 1.21 species in post-monsoon and decreased again to lowest 5.75 ± 0.79 species in winter with $p < 0.01$ ($F_{(3,41)}$ 4.97).

Differences among the reservoirs

The differences in mean seasonal species richness among the three habitats in all the seasons were non-significant ($p > 0.05$). In monsoon, post-monsoon and winter higher mean species richness was recorded at JIR while lower at TIR with $F_{(2,26)}$ 2.73, $F_{(2, 25)}$ 2.01 and $F_{(2,32)}$ 3.13 respectively. In summer maximum mean species richness was observed at WIR while minimum at TIR ($F_{(2, 33)}$ 2.12).

Density

As recorded for the species richness the density was also found to be highest during post-monsoon while lowest in winter.

Seasonal variations around Each Reservoir

TIR- The mean density of Odonates was 0.28 ± 0.15 individuals/10m^2/min in summer which was maintained at 0.24 ± 0.09 individuals/10m^2/min in monsoon and was found to be highest 0.74 ± 0.32 individuals/10m^2/min in post-monsoon. It decreased to the minimum 0.05 ± 0.04 individuals/10m^2/min in winter. The seasonal variations were non-significant ($p > 0.05$, $F_{(3,41)}$ 2.58).

JIR - The mean density showed the same trend as recorded for TIR but with higher density 0.39 ± 0.11 individuals/10m^2/min in summer which was almost maintained at 0.31 ± 0.12 individuals/10m^2 /min in monsoon but was found to be highest 0.63 ± 0.18 individuals/10m^2 /min in post-monsoon and decreased to the lowest 0.20 ± 0.19 individuals/10m^2/min in winter. The seasonal variations were non-significant ($p > 0.05$, $F_{(3,34)}$ 1.16).

WIR- Subtle different trend was observed at WIR compared to other two reservoirs where the density was 0.27 ± 0.14 individuals/10m^2/min in summer which increased to 0.74 ± 0.36 individuals/10m^2/min in monsoon and further to 1.36 ± 0.25 individuals/10m^2/min in post-monsoon and dropped significantly to 0.21 ± 0.12 individuals/10m^2/min in winter. The seasonal variations were moderately significant ($p < 0.01$, $F_{(3,41)}$ 5.16).

Differences among the reservoirs

The differences in the mean density of odonates among the three reservoirs were non-significant ($p > 0.05$) in all seasons of the year. The mean density of Odonates in summer was recorded to be highest at JIR while it was almost same at TIR and WIR ($F_{(2, 33)}$ 0.25). In monsoon the highest mean density of Odonates was recorded at WIR while lowest at TIR with $F_{(2, 26)}$ 1.25, during post-monsoon also highest mean density was recorded at WIR while lowest at JIR with non significant differences ($F_{(2, 26)}$ 1.92). Although the lowest densities were recorded in winter at all the three reservoirs, among the three it was lowest at TIR and almost same at the other two reservoirs ($F_{(2, 32)}$ 0.51).

Shannon Weiner Species Diversity Index (H')

Mean Shannon weiner diversity index for odonates also showed non-significant differences for seasonal variations at all the three reservoirs. H' was found to be highest in post-monsoon while lowest in winter.

Seasonal variations around Each Reservoir

TIR – The mean diversity index of Odonates at TIR was same 1.35 ± 0.19 and 1.35 ± 0.17 in summer and post-monsoon respectively while lowest 0.94 ± 0.15 in winter and moderate 1.23 ± 0.2 in monsoon ($p > 0.05$, $F_{(3,41)}$ 1.27).

JIR – At JIR, mean H' was 1.48 ± 0.13 in summer which increased marginally to 1.65 ± 0.16 in monsoon and was maintained at 1.69 ± 0.18 in post-monsoon while was found to be lowest 1.14 ± 0.22 in winter indicating no significant seasonal variations ($p > 0.05$, $F_{(3,34)}$ 1.94).

WIR – At WIR same trend as that of JIR was noted with 1.42 ± 0.17 H' in summer increasing to 1.57 ± 0.08 in monsoon and further to 1.83 ± 0.14 in post-monsoon and was lowest 1.27 ± 0.19 in winter. The seasonal differences varied non-significantly ($p > 0.05$, $F_{(3,41)}$ 2.25).

Differences among the reservoirs

In summer, the diversity index was noted to be highest for JIR and lowest for TIR. The differences among the three reservoirs in summer showed non-significant differences ($p > 0.05$, $F_{(2,33)}$ 0.15). In monsoon too, it was highest for JIR while lowest for TIR ($p > 0.05$, $F_{(2,26)}$ 2.19). However, in post-monsoon, mean H' was highest for WIR while lowest for TIR. The differences among the reservoirs were non-significant ($p > 0.05$, $F_{(2,25)}$ 2.5) in this season. In winter too, same trend as that of post-monsoon was observed with maximum H' for WIR and minimum for TIR with non-significant ($p > 0.05$, $F_{(2,32)}$ 0.82) differences.

Evenness (E)

Minor variations were observed in the seasonal mean Evenness and hence the differences varied non-significantly ($p > 0.05$) amongst the reservoirs during all seasons. It ranged between 0.6 to 0.8.

Seasonal variations around Each Reservoir

TIR – Highest mean evenness 0.81 ± 0.11 was noted in winter while during rest of the seasons the mean evenness was comparatively low with 0.7 ± 0.09 in summer, 0.71 ± 0.1 in monsoon and 0.69 ± 0.06 in post-monsoon ($p > 0.05$, $F_{(3,41)}$ 0.35).

JIR – At JIR, mean evenness was highest 0.75 ± 0.07 in monsoon and lowest 0.59 ± 0.12 in winter, while it was 0.72 ± 0.07 and 0.7 ±0.07 in summer and post-monsoon respectively ($p > 0.05$, $F_{(3,34)}$ 0.59).

WIR – Mean seasonal evenness was 0.61 ± 0.07 in summer at WIR which increased non-significantly to 0.79 ± 0.04 in monsoon and further to 0.81 ± 0.05 in post-monsoon but decreased to 0.68 ± 0.1 in winter ($p > 0.05$, $F_{(3,41)}$ 1.66).

Differences among the reservoirs

In summer maximum mean evenness was recorded for JIR closely followed by TIR and minimum at WIR ($p > 0.05$, $F_{(2,33)}$ 0.51) while during following season monsoon, maximum mean E was recorded for WIR while minimum for TIR ($p > 0.05$, $F_{(2,26)}$ 0.31). In post-monsoon too maximum mean Evenness was noted at WIR while at TIR and JIR it was almost same ($p > 0.05$, $F_{(2,25)}$ 1.48). During winter highest mean evenness was recorded for TIR while lowest for JIR ($p > 0.05$, $F_{(2,32)}$ 0.94).

Annual Percentage Occurrence (Table 3.6, Figure 3.7)

As mentioned earlier of the total 8 families recorded in the study, 7 families were present at TIR while family Protoneuridae was absent. At JIR only 5 families were present and families Aeshnidae and Cordulegasteridae along with Protoneuridae were absent. While at WIR 6 families were present and the families Aeshnidae of Anisoptera and Platycnemididae of Zygoptera were not represented.

TIR –When the percentage occurrence is compared on annual scale it is observed that Libellulidae (Anisoptera) is the most dominant family with highest 66.06 % of the species followed by Coenagrionidae (Zygoptera) with 20.07%, Gomphidae (Anisoptera)

8.76%, Platycnemididae (Zygoptera) 2.55% Lestidae (Zygoptera) 1.46%, Cordulegasteridae (Anisoptera) 0.73% and Aeshnidae (Anisoptera) 0.36%.

JIR – At JIR only 5 families were represented with Libellulidae being the most dominant family with 70.28% while Coenagrionidae followed with 25.08% occurrence, Gomphidae had 3.72% and Lestidae and Platycnemididae with very low percentages of 0.62% and 0.31% respectively.

WIR – Six families were represented around WIR again with Libellulidae dominating with 63.95% of the total odonates while Coenagrionidae constituted 26.32% followed by Gomphidae 8.16%, Lestidae 1.05% and Protoneuridae and Cordulegasteridae 0.26% each.

Differences among the reservoirs

When the comparison is made among three habitats, Libellulidae was the most dominant family with maximum percentage occurrence at JIR. Coenagrionidae followed Libellulidae but had highest percentage occurrence around WIR while Lestidae had the highest percentage occurrence around TIR. Family Protoneuridae was absent around TIR and JIR, and Platycnemididae around WIR. Aeshnidae was absent at JIR and WIR. Gomphidae had more or less same percentage of occurrence at TIR and WIR while lower percentage at JIR and Cordulegasteridae had higher percentage at TIR while it was absent at JIR.

Seasonal Percentage Occurrence (Table 3.7, Figure 3.8)

As was evident in the annual scenario, the seasonal percentage occurrence also clearly indicated highest percentage of Family Libellulidae (Dragonflies - Anisoptera) in all the seasons at the three reservoirs. When considered in hierarchal orders family Libellulidae with families Coenagrionidae and Gomphidae were the three families represented all throughout the year at all the three reservoirs. During monsoon Lestidae (Damselflies) was absent around all the reservoirs while it was present only around TIR in post-monsoon and at JIR in winter with low presence at all the reservoirs during summer. Protoneuridae (Damselflies) was present only at WIR that too only during summer while over rest of the year it was absent. Platycnemididae (Damselflies) was totally absent at WIR while it was present only during winter around JIR and in all seasons except winter around TIR. Aeshnidae (Dragonflies) was observed only at TIR that too only during summer while Cordulegasteridae (Dragonflies) occurred in summer at WIR while during monsoon and post-monsoon at TIR.

Seasonal differences around reservoirs

When seasonal difference in percentage occurrence of odonates around each reservoir are considered, different families in a particular season at each reservoir are taken into consideration.

Summer

TIR – Libellulidae accounted for 73.81% of the total odonates followed by Coenagrionidae with 13.1%, Gomphidae 7.14% and Lestidae 3.57%. Platycnemididae and Aeshnidae each constituted 1.19% of total Odonates in this season.

JIR – At JIR, 82% of the Odonates were contributed by family Libellulidae while only 14% by family Coenagrionidae. The percentage contributed by other families was very low with family Gomphidae contributing 3% while Lestidae just 1%.

WIR –Around WIR also family Libellulidae constituted nearly 73% of the total Odonates in summer while Coenagrionidae constituted 12.17% and Gomphidae 9.57%. Family Lestidae constituted 3.48% while families Protoneuridae and Cordulegasteridae constituted 0.87% each.

Monsoon

TIR- In monsoon also family Libellulidae contributed maximum 67.21% of the total Odonates, while Coenagrionidae contributed 16.39%, closely followed by Gomphidae with 9.84% and Platycnemididae 4.92%. Cordulegasteridae had low percentage occurrence of 1.64.

JIR – In monsoon only 3 families were represented around JIR with highest 73.68% of Libellulidae, 21.05 % Coenagrionidae and 5.26% Gomphidae.

WIR – Around WIR also only these 3 families were represented during monsoon with 63.22% Libellulidae, 29.89% Coeanagrionidae and 6.9% Gomphidae.

Post-monsoon

TIR – Family Libellulidae constituted 58.06%, and family Coenagrionidae 25.81% of the total odonates with 10.75% of family Gomphidae. Family Platycnemididae, Lestidae and Cordulegasteridae had low percentage occurrence of 3.23%, 1.08% and 1.08% respectively.

JIR – As in monsoon, during post-monsoon too JIR had presence of only three families Libellulidae 70.37%, Coenagrionidae with 25.93% and Gomphidae with 3.7%.

WIR – WIR also showed presence of these three families *i.e.* Libellulidae with maximum 55.05%, Coenagrionidae 33.03% and Gomphidae 11.93%.

Winter

TIR **–** Only three major families were represented around TIR in winter with 66.67% of total Odonates contributed by Libellulidae, 27.78% by Coenagrionidae and 5.56% by Gomphidae.

JIR – At JIR, all five families reported were present in winter with 48.48% of Libellulidae, 45.45% Coenagrionidae while Gomphidae along with Platycnemididae and Lestidae had minor representation of 3.03% for the former and 1.52% each for the later two.

WIR- At WIR again only three major families were represented with 63.77% Libellulidae, 34.78% Coenagrionidae and 1.45% Gomphidae.

Differences among the habitats

Coenagrionidae had comparatively higher representation at JIR during summer and winter while at WIR it was more prevalent in monsoon and post-monsoon. Amongst the three reservoirs, Lestidae though not common, was observed more frequently at TIR in summer and post-monsoon, at WIR only in summer and at JIR in summer as well as winter. Protoneuridae was present only during summer that also only at WIR. Platycnemididae was observed around TIR in three seasons as compared to single appearance in the fourth season winter at JIR. Aeshnidae was also observed only at TIR during summer. Gomphidae had overall low occurrence at JIR among the three reservoirs where its percentage never increased beyond 5%. This family was more common during post-monsoon at TIR and WIR. Cordulegasteridae appeared at TIR in monsoon and post-monsoon while during summer at WIR. JIR had the highest percentage of Libellulidae among the three reservoirs in all seasons except winter when the percentage was lower than that at TIR and WIR.

Variations along Seasons in three major families at each reservoir

Libellulidae – At JIR decrease in the percentage occurrence was observed from summer to winter, while at TIR and WIR the decrease was up to post-monsoon while increase was noted in winter.

Coenagrionidae – A trend of increase in the percentage occurrence from summer up to winter was observed for this family at all the three reservoirs.

Gomphidae – At TIR, the percentage occurrence of this family increased from summer through monsoon to post-monsoon and declined significantly to minimum in winter. At JIR, more or less same percentage occurrence was observed in all the seasons except monsoon when it was higher, while at WIR, it oscillated with higher percentage in summer which decreased in monsoon, increased to maximum percentage in post-monsoon and declined again to minimum in winter.

Table 3.1: Number of species belonging to different families of order Odonata at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Coe (13)	**Les(3)**	**Pro (1)**	**Pla (1)**	**Aes (1)**	**Gom (2)**	**Cor (1)**	**Lib (23)**	**Total**
TIR	9	2	0	1	1	2	1	19	35
JIR	12	1	0	1	0	2	0	21	37
WIR	10	2	1	0	0	2	1	19	35

Coe – Coengrionidae, Les –Lestidae, Pro – Protoneuridae, Pla – Platycnemididae, Aes – Aeshnidae, Gom – Gomphidae, Cor - Cordulegasteridae, Lib- Libellulidae

Table 3.2: Abundance rating of Odonate species encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Abundant	**Common**	**Frequent**	**Uncommon**	**Rare**
TIR	0	5	4	10	16
JIR	0	4	9	8	16
WIR	3	5	4	11	12

Table 3.3: Annual and Seasonal Jaccard's similarity Index for odonates between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Annual		**Summer**		**Monsoon**		**Post monsoon**		**Winter**	
	TIR	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**
WIR	0.63	0.64	0.5	0.59	0.54	0.68	0.49	0.59	0.56	0.47
JIR	0.71	-	0.51	-	0.52	-	0.65	-	0.46	-

Table 3.4: Annual Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of Odonates at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Species Richness (**) $\mathbf{F_{(2,125)} 6.48}$	Density (ns) $\mathbf{F_{(2,125)} 2.22}$	Shannon Weiner index (*) $\mathbf{F_{(2,125)} 3.37}$	Evenness (ns) $\mathbf{F_{(2,125)} 0.28}$
TIR	6.09 ± 0.53	0.32 ± 0.1	1.21 ± 0.09	0.73 ± 0.05
JIR	8.71 ± 0.64	0.36 ± 0.08	1.46 ± 0.09	0.68 ± 0.05
WIR	8.44 ± 0.56	0.61 ± 0.13	1.51 ± 0.08	0.72 ± 0.04

Table 3.5: Seasonal variations in the Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of Odonates at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

			Summer	**Monsoon**	**Post monsoon**	**Winter**
Species Richness		**Among Reservoirs** / **Within Reservoirs**	(ns) $F_{(3,33)}$ **2.12**	(ns) $F_{(2,26)}$ **2.73**	(ns) $F_{(2,25)}$ **2.01**	(ns) $F_{(2,32)}$**3.13**
	TIR	**(***) $F_{(3,41)}$ 7.03**	7 ± 0.88	6.1 ± 1.07	8.46 ± 1.12	3 ± 0.39
	JIR	**(*) $F_{(3,34)}$ 3.84**	9 ± 0.85	9.5 ± 0.91	11.57 ± 1.11	6 ± 1.45
	WIR	**(**)$F_{(3,41)}$ 4.97**	9.58 ± 1.05	7.91 ± 0.95	10.9 ± 1.21	5.75 ± 0.79
Density			**(ns) $F_{(3,33)}$ 0.25**	**(ns) $F_{(2,26)}$ 1.25**	**(ns) $F_{(2,25)}$1.92**	**(ns) $F_{(2,32)}$0.51**
	TIR	**(ns) $F_{(3,41)}$ 2.58**	0.28 ± 0.15	0.24 ± 0.09	0.74 ± 0.32	0.05 ± 0.04
	JIR	**(ns) $F_{(3,34)}$ 1.16**	0.39 ± 0.11	0.31 ± 0.12	0.63 ± 0.18	0.20 ± 0.19
	WIR	**(**)$F_{(3,41)}$ 5.16**	0.27 ± 0.14	0.74 ± 0.36	1.36 ± 0.25	0.21 ± 0.12
Shannon Weiner index (H')			**(ns) $F_{(3,33)}$ 0.15**	**(ns) $F_{(2,26)}$ 2.19**	**(ns) $F_{(2,25)}$ 2.5**	**(ns) $F_{(2,32)}$ 0.82**
	TIR	**(ns) $F_{(3,41)}$1.27**	1.35 ± 0.19	1.23 ± 0.2	1.35 ± 0.17	0.94 ± 0.15
	JIR	**(ns) $F_{(3,34)}$ 1.94**	1.48 ± 0.13	1.65 ± 0.16	1.69 ± 0.18	1.14 ± 0.22
	WIR	**(ns) $F_{(3,41)}$ 2.25**	1.42 ± 0.17	1.57 ± 0.08	1.83 ± 0.14	1.27 ± 0.19
Evenness (E)			**(ns) $F_{(3,33)}$ 0.51**	**(ns) $F_{(2,26)}$ 0.31**	**(ns) $F_{(2,25)}$ 1.48**	**(ns) $F_{(2,32)}$ 0.94**
	TIR	**(ns) $F_{(3,41)}$ 0.35**	0.7 ± 0.09	0.71 ± 0.1	0.69 ± 0.06	0.81 ± 0.11
	JIR	**(ns) $F_{(3,34)}$ 0.59**	0.72 ± 0.07	0.75 ± 0.07	0.7 ±0.07	0.59 ± 0.12
	WIR	**(ns) $F_{(3,41)}$ 1.66**	0.61 ± 0.07	0.79 ± 0.04	0.81 ± 0.05	0.68 ± 0.1

Table 3.6: Annual Percentage Occurrence of the Odonate families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Coe	Les	Pro	Pla	Aes	Gom	Cor	Lib
TIR	20.07 %	1.46 %	0 %	2.55 %	0.36 %	8.76 %	0.73 %	66.06 %
JIR	25.08%	0.62 %	0 %	0.31 %	0 %	3.72 %	0 %	70.28 %
WIR	26.32%	1.05 %	0.26%	0 %	0 %	8.16 %	0.26 %	63.95 %

Coe – Coengrionidae, Les –Lestidae, Pro – Protoneuridae, Pla – Platycnemididae, Aes – Aeshnidae, Gom – Gomphidae, Cor - Cordulegasteridae, Lib- Libellulidae

TABLE 3.7: Seasonal Percentage Occurrence of the Odonate families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Summer			Monsoon			Post-monsoon			Winter		
	TIR	JIR	WIR	TIR	JIR	WIR	TIR	JIR	WIR	TIR	JIR	WIR
Coenagrionidae	13.1	14	12.17	16.39	21.05	29.89	25.81	25.93	33.03	27.78	45.45	34.78
Lestidae	3.57	1	3.48	0	0	0	1.08	0	0	0	1.52	0
Protoneuridae	0	0	0.87	0	0	0	0	0	0	0	0	0
Platycnemididae	1.19	0	0	4.92	0	0	3.23	0	0	0	1.52	0
Aeshnidae	1.19	0	0	0	0	0	0	0	0	0	0	0
Gomphidae	7.14	3	9.57	9.84	5.26	6.9	10.75	3.7	11.93	5.56	3.03	1.45
Cordulegasteridae	0	0	0.87	1.64	0	0	1.08	0	0	0	0	0
Libellulidae	73.81	82	73.04	67.21	73.68	63.22	58.06	70.37	55.05	66.67	48.48	63.77

Table 3.8- Abundance rating of the Odonates observed around three reservoirs

Sr. No.	Common Name	Scientific Name	TIR	JIR	WIR
	Sub-order – Zygoptera				
	Family: Coenagrionidae				
1	Coromandel Marsh Dart	*Ceriagrion coromandelianum*	U	F	U
2	Blue Grass Dartlet, Blue Sprite	*Pseudagrion microcephalum*	U	U	F
3	Golden Dartlet	*Ischnura aurora*	R	F	U
4	Senegal Golden Dartlet	*Ischnura senegalensis*	C	F	C
5	Pigmy Dartlet	*Agriocnemis pygmaea*	U	U	U
6	Black marsh dart	*Onychargia sp.*	R	F	F
7	Rusty Marsh Dart	*Ceriagrion olivaceum*	R	R	R
8	Common orange	*Ceriagrion sp.*	R	R	U
9	Painted Sprite Damselfly	*Pseudagrion sp.*		R	R
10	Common blue damselfly	*Enallagma sp.*		R	U
11		*Ischnura sp*	R	R	
12		*Agriocnemis sp*		R	
	Family: Lestidae				
13	Green Emerald	*Lestes virdis*	R		R
14	Emerald spreadwing	*Lestes dryas*		R	R
15	Common Spreadwing	*Lestes sponsa*	R		
	Family: Protoneuridae				
16	Blue Bambootail				R
	Family: Playtcnemididae				
17	Yellow Bush Dart	*Copera marginipes*	U	R	
	Sub-order Anisoptera				
	Family: Aeshnidae				
18	Hawker Dragonfly	*Aeshna sp.*	R		
	Family: Gomphidae				
19	Common clubtail	*Ictinogomphus rapax*	C	U	C
20	Snaketail	Ophiogomphus sp.	R	R	U
	Family: Cordulegasteridae				
21	Spiketail	*Cordulegaster sp*	R		R
	Family: Libellulidae				
22	Wandering Glider	*Pantala flavescens*	C	F	C
23	Ditch Jewel	*Brachythemis contaminata*	C	C	A
24	Long - legged Marsh Glider	*Trithemis pallidinervis*	C	F	A
25	Ruddy marsh skimmer	*Crocothemis servilia*	F	C	A
26	Common Scarlet Darter	*Crocothemis erythraea*	F	F	C
27	Ground skimmer	*Diplacodes trivialis*	F	F	C
28	Black Percher	*Diplacodes lefebvrii*	U	C	U
29	Black-tipped Percher	*Diplacodes nebulosa*			R
30	Pygmy Skimmer	*Tetrathemis platyptera*			R
31	Common Picture Wing	*Rhyothemis variegata*	U	C	U
32	Yellow-tailed Ashy Skimmer	*Potamarcha congener*		R	R
33	Crimson marsh glider	*Trithemis aurora*	U	U	F
34	Orange winged Dropwing	*Trithemis kirbyi*	U	U	U
35	Granite Ghost	*Bradinopyga geminata*	F	U	F
36	Blue Marsh Hawk	*Orthetrum glaucaum*	U	R	
37	Black-tailed Skimmer	*Orthetrum cancellatum*		U	
38	Blue-tailed Forest Hawk	*Orthetrum triangulare*		R	
39	Slender skimmer	*Orthetrum sabina*	R	R	R
40	Black Pennant	*Selysiothemis sp.*	R	R	R
41	Vagrant Darter	*Sympetrum vulgatum*	U	F	U
42	Meadow hawk Dragonfly	*Sympetrum commixtum*	R		R
43	Meadow hawk Dragonfly	*Sympetrum sp.*	R	R	U
44		*Brachydiplax sp.*	R	R	
45	Demon Dragonfly	*Indothemis sp.*	R	U	

Figure 3.1: Number of species belonging to different families of order Odonata at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

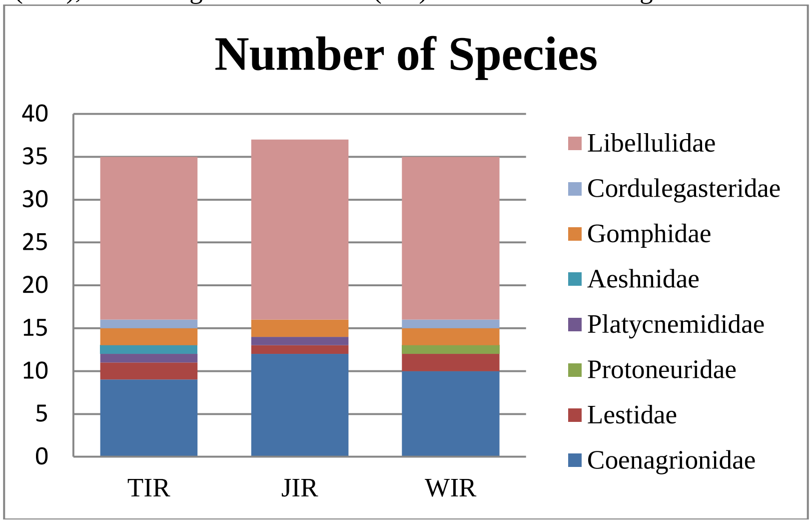


Figure 3.2: Abundance rating of the Odonate species encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

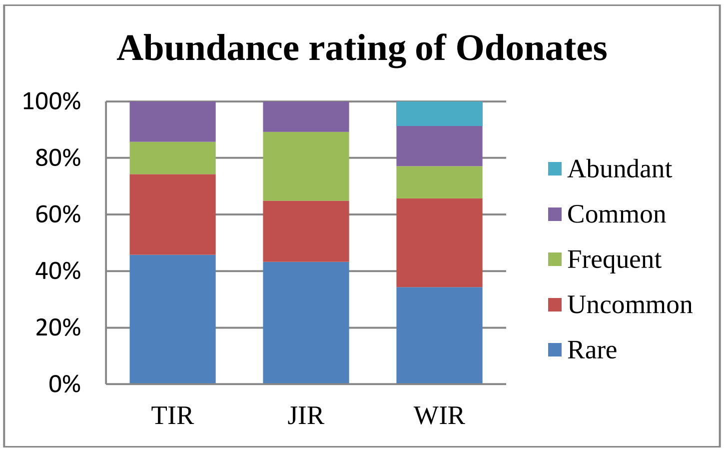


Figure 3.3: Annual Jaccard's similarity Index for odonates between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

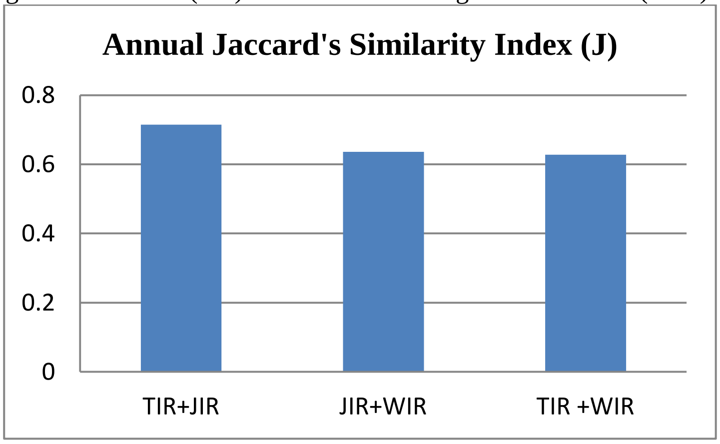


Figure 3.4: Seasonal Jaccard's similarity Index for odonates between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

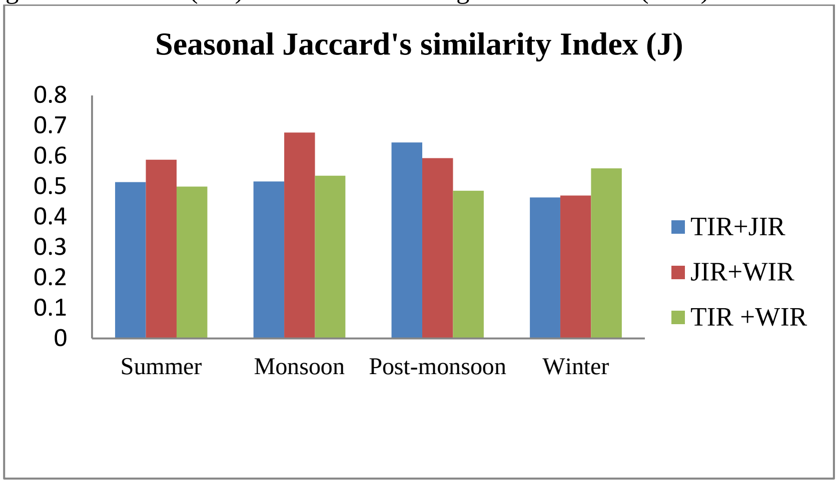
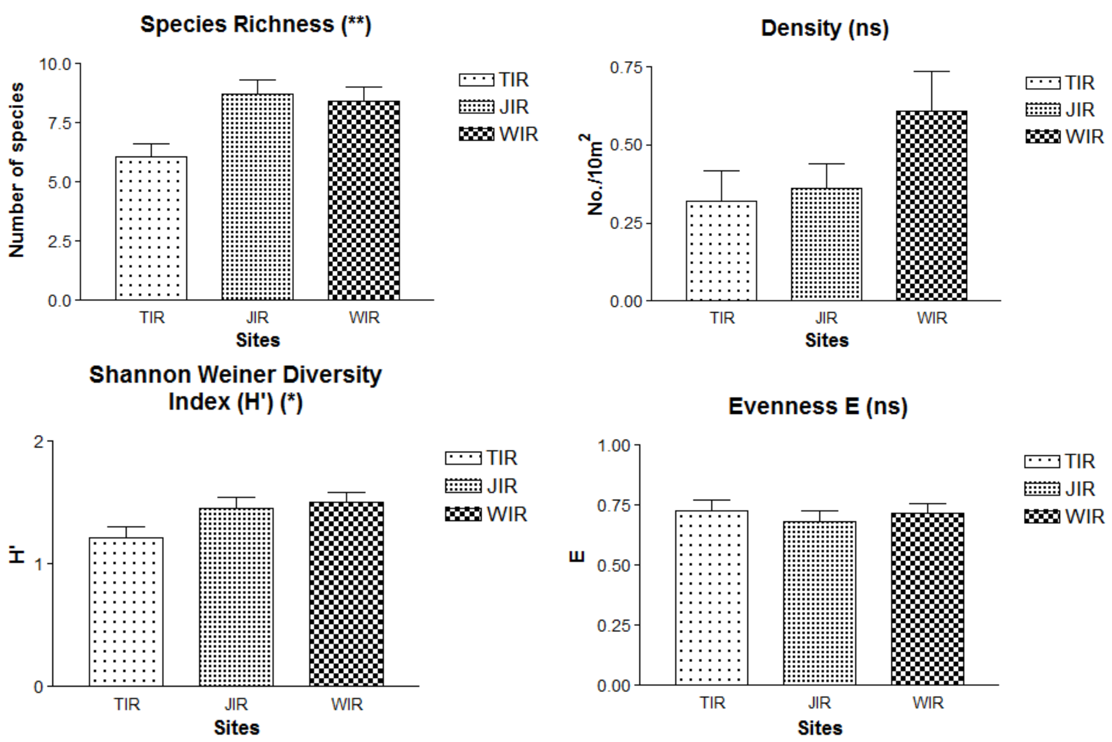
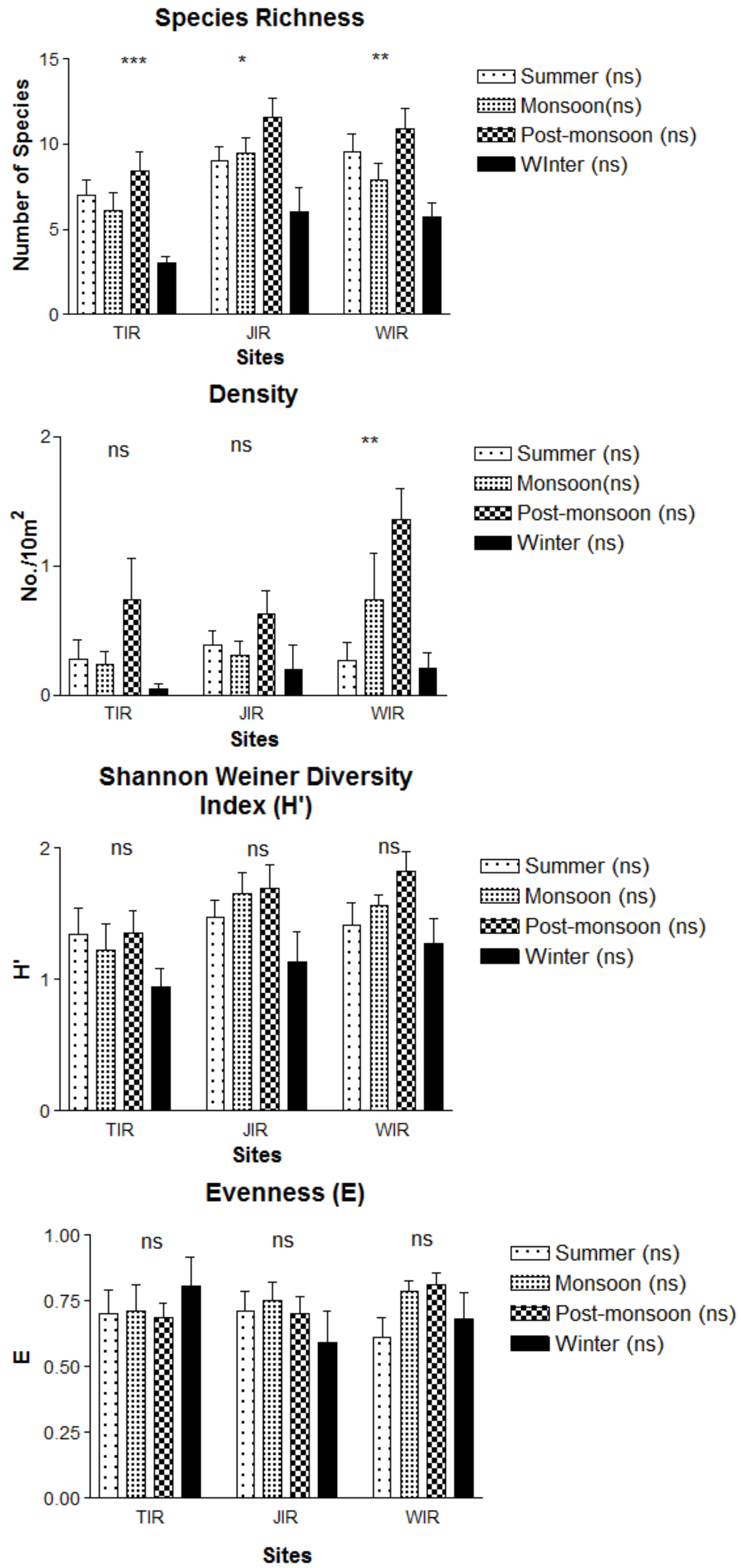


Figure 3.5 : Annual Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of Odonates at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

Figure 3.6 : Seasonal variations in the Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of Odonates at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

Figure 3.7: Annual Percentage Occurrence of the Odonate families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

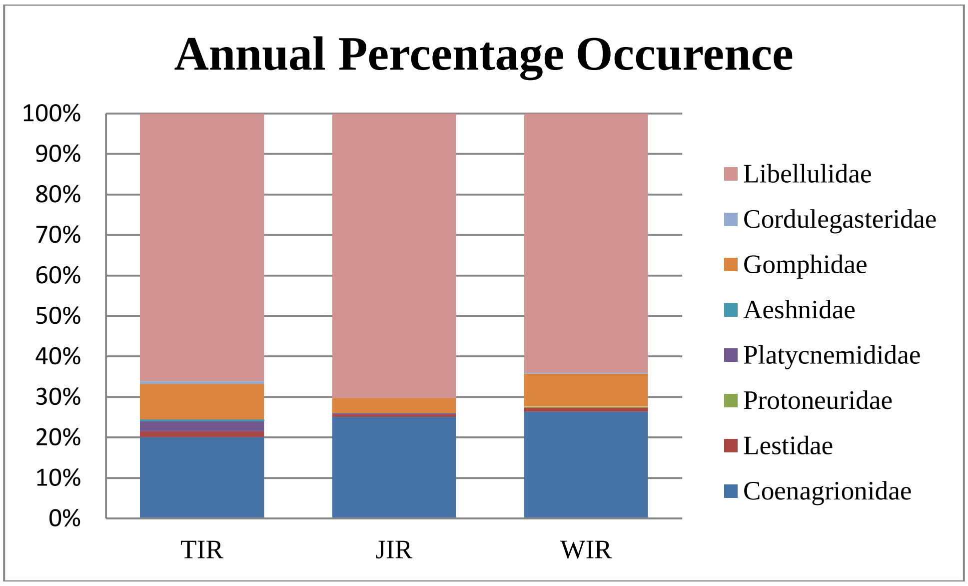


Figure 3.8: Seasonal Percentage Occurrence of the Odonate families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

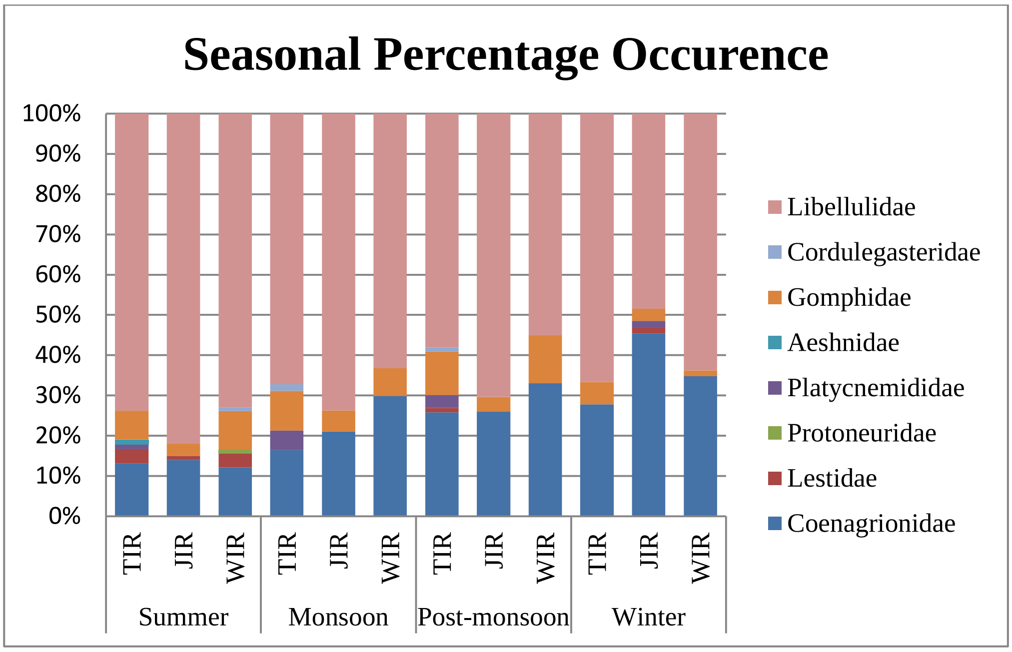


PLATE 8: SOME OF THE ODONATES OBSERVED IN THE STUDY

Dragonflies

Brachythemis contaminate (Ditch Jewel)

Trithemis pallidinervis (Long legged Marsh Skimmer)

Diplocodes trivialis (Ground Skimmer)

Dragonflies

Crocothemis servilia (Ruddy marsh skimmer)

Rhyothemis variegate (Common Picture wing)

Ictinogomphus rapax (Common Clubtail)

Crocothemis erythaea (Common Scarlet Darter)

Pantala flavescens (Wandering glider)

DAMSELFLIES

Ischnura senegalensis (Senegal Golden Dartlet)

Pseudagrion microcephalum (Blue Grass Dartlet)

*Ceriagrion coromandelianum (*Coromandel Marsh Dart *)*

*Copera marginipes (*Yellow marsh Dart*)*

Ischnura aurora (Golden Dartlet)

*Enallagma sp. (*Common blue damselfly*)*

Discussion

Odonates being one of the most diverse groups of insects with well evolved flight mechanism have recently engrossed the attention of large group of entomologists leading to the initiation of several studies giving their description, distribution and habitat preference. Many of the Odonate families are known to prefer the flowing water for breeding while there are others that use stagnant water. However, as the Odonate larvae are aquatic, water forms an important component in their life cycle. Odonata is a comparatively smaller order of Class Insecta with only 5680 described species worldwide (Kalkman *et al.* 2008) with the majority occurring in tropics (Miller, 2007). However, India has an exceptionally rich and interesting odonate fauna with over 10% (about 600 species) of the world's species (Fraser, 1933; 1934; 1936; Tyagi, 1997). India's Odonate fauna being poorly known there is a great need for basic information on their occurrence, distribution and seasonality (Miller, 2007).

Majority of species of both suborders of Odonates, the Zygopterans and Anisopterans, mainly prefer sunny biotopes with exposed macrophytes (Clausnitzer, 2003) and hence good number of Odonates were observed around three open irrigation reservoirs in sub-tropical semi arid zone which has good sunlight and almost no tall vegetation in immediate vicinity – the favourable conditions for this insect group.

Habitat diversity and connectivity along with the hydrological dynamics are important for the dragonflies (Clausnitzer, 2006). The irrigation reservoirs of the present study where variety of micro-habitats are present together with the presence of the alternate scrubland habitat in the surroundings support the prey base for this group. Hence, good diversity of Odonates was observed in the area. Different ecological requirements are linked to different dispersal capacities. Species with narrow niches disperse poorly, while the species with broad niche become pioneers of temporal habitats (often created by disturbance) and are excellent colonizers (Clausnitzer, 2006). Odonates are the top predators in many of naturally fishless habitats (McPeek, 1998), and produce cascading effects due to their assemblages. These assemblages also influence overall richness and diversity of ecosystems (Reece and Mcintyre, 2009). Hence, the presence of Odonates in any habitat can act as the indication of the higher species richness supported by that ecosystem.

Reports on Indian Odonates are contradicting. According to the study conducted by Prasad (1999), Indian Odonate fauna comprises 499 species representing 17 families and 3 sub-orders. However, after a decade Subramaniam (2009) reported the presence of 470 species belonging to 139 genera 19 families and 3 sub-orders. 2 new families reported by the latter were not reported by Prasad (1999). Over a span of 10 years nearly 30 species either were not identified due to lack of proper identification keys or have become extinct. Though a good knowledge of their ecological requirements, distribution and seasonality is available (Maiolini and Carolli, 2009) there is an immediate need to document and conserve the habitats for these beautiful insects.

Of the total 470 species of Odonates recorded from India (Subramaniam, 2009) 45 species were recorded in the smaller areas of present study. Subramaniam (2009) reported nearly 267 species of Anisoptera belonging to 7 families and 195 species of Zygoptera belonging to 11 families, of which nearly 28 Anisopteran species belonging to 4 families and 17 Zygopteran species belonging to 4 families were recorded from the present study. In this area, the number of Anisopterans was higher as compared to Zygopterans. This scenario has also been recorded in the study conducted by Arulprakash and Gunathilagaraj (2008) in temporary pools of Coimbatore and Salem. The differences in number could be due to the high dispersal ability of Anisopterans (Batzer and Wissinger, 1996; Williams, 1997; Lawler, 2001; Kadoya *et al.,* 2004) and their adaptability to the wide range of habitats (Hodgkin and Watson, 1958; Suhling *et al*., 2004, 2005). Damselflies have limited dispersal ability (Weir 1974) and less preference to not only environment offered by the temporary water bodies (Williams, 1997; Kadoya *et* *al*., 2004) but also to partial or absence of shade cover as well (Clark and Samways, 1996). Shade and aquatic vegetation favour Zygoptera more than Anisoptera (Subramaniam, 2005).

The two largest families Coenagrionidae of damselflies and Libellulidae of dragonflies (Kalkman *et al.*, 2008) were dominant in present study too. These two families are considered to be of recent origin (Rehn, 2003). Almost all ubiquitous odonate species belonging to these two families dominate in unshaded habitats with stagnant water (both artificial and natural). Both families include species with the greatest migratory capacity, including those with distributions spanning more than one continent and almost all species found on isolated islands (Kalkman *et al.*, 2008).

In majority of the studies conducted in the Indian sub-continent, these two families have been rated as the most species rich families (Gunathilagaraj *et al.,* 1999; Asaithambi and Manickavasagam, 2002; Kandibane *et al.,* 2003; Emiliyamma, 2005; Miller, 2007; Sharma and Joshi, 2007; Sharma *et al.,* 2007; Subramaniam, 2007; Sharma *et al.,* 2009; Rangnekar *et al.*, 2010). Nearly same numbers of species (35 each at TIR and WIR and 37 species at JIR) were recorded from the three habitats which are only about 25 to 50 kms away from each other. However their occurrence and seasonality varied probably because of the microhabitat characteristic of each. Urbanization does not affect the dragonfly diversity (Lubertazzi and Ginsberg, 2010) and hence no major effect of the human activities was found in the present study as the number of Odonates was almost same at the reservoir (TIR) nearer to Vadodara city. However, the human presence has been reported to disturb Odonates (Bried, 2005; Maiolini and Carolli, 2009) and lead to their frequent appearance and disappearance in the area. Further, though the size of the water bodies are known to determine the species richness and diversity of Odonata (Lounibos *et al.* 1990; Clark and Samways, 1996; Stewart and Samways, 1998; Schindler *et al.,* 2003; Kadoya *et al.*, 2004; Carchini *et al.*, 2005; Suh and Samways,

2005) no major difference in the Odonata diversity was recorded amongst the three reservoirs.

In the present study, the habitats selected are the reservoirs, basically the lentic ecosystems. According to Subramaniam *et al*., (2008) and Subramaniam, (2009) lentic habitats are believed to increase the species richness of an area, but can also potentially encourage colonization of widespread generalist species such as Libellulids. Among Anisoptera, Libellulidae with more than 1000 species is the most dominant family and is justified as the largest dragonfly family in the world. It has 85 species reported in India. Members of families Aeshnidae, Cordulegastridae and Gomphidae that prefer breeding in running water of streams and rivers for breeding (Miller, 2007) were not well represented in the present study.

Though Coenagrionidae is the largest zygopteran family with more than 1000 species recorded over the world only 58 species are recorded from India (Subramaniam, 2009) and only 12 species in the present study. Coenagrionidae is generally referred as the Narrow winged damselflies or Pond damselflies restricted to stagnant water. Hence, they were found to be more common around the reservoirs where the water flow is slow. Another family that prefers ponds and swamps is Lestidae a small family of the Spread wings. Though their distribution is cosmopolitan their presence around the reservoirs was rare as they might prefer smaller water bodies. Similarly, Platycnemididae and Protoneuridae though having considerable numbers of species in India were represented by single species each as they are very sensitive to habitat modifications. They disappear completely in the absence of the suitable conditions (Subramaniam *et al*., 2008). The fluctuating water levels over the season with parallel changes in the hydro period and water spread in the monsoon dependent reservoirs probably do not provide suitable stable habitat for these families. Hence they were among the rare families in the present study. Of the two, Protoneuridae is generally known to prefer the slow flowing streams in the forests where the disturbances are less whereas the habitats selected in the present study are open and away from forests. This family was completely absent at TIR and JIR while observed just once at WIR which is comparatively undisturbed area only at 25 Kms. distance from the forest of the Jambughoda wildlife Sanctuary. All Protoneurids breed in running waters and most of them are restricted to forested landscapes, and hence are common in the Western Ghats of Peninsular India (Subramaniam, 2005). Family Platycnemididae is also known to be more common in the habitats with running waters of rivers and streams. It is known to prefer breeding in the mountainous stream (Subramaniam, 2005), hence was not so common around the reservoirs in the flat land of Central Gujarat.

Abundance Rating

The number of species that are accidental in appearance and rare is always higher as compared to the abundant species (Krebs, 1985). In the present study too, 40-50% of the odonates were rated as rare. Species with specific habitat requirements can become rarer due to environmental degradation (Moore, 1982) as they have to explore newer habitats for colonization. They may be accidental in the areas to which they are not adapted. For these rare odonates survival through emergence is particularly worthy as it is the period of substantial mortality (Crowley *et al.,* 1987). Hence, abundance of species is spatially and temporally variable. Some species are abundant, some are rare, and the rest are in between (Rageai and Allam, 1978). Presence of 3 species abundant at WIR and none at TIR and JIR indicate the differences at regional level. These three species *Brachythemis contaminate, Trithemis pallidinervis* and *Crocothemis servilia* of family Libellulidae are the most common species in India preferring lentic habitat.

Brachythemis contaminate is found in any kind of water body may that be polluted or unpolluted. This species prefers perching on the low vegetation or ground in the vicinity of water, sometimes on water surface making occasional short flights (Miller, 2007) to capture flying insects like Diptera, Ephemeroptera and Plecoptera (Mitra, 2007). However, it also feeds on other smaller insects like ants, aphids, *etc*. which were abundant in the area (Chapters 4 and 6). This species was found all throughout the year but their number was maximum during summer and post-monsoon.

Trithemis pallidinervis, a widely distributed species of India was commonly found at WIR especially during winter when other species were not observed. It perches on prominent places of vegetation about 1m above the ground, facing wind and close to water edge (Miller, 2007) as was also observed in summer and post-monsoon in the present study.

Crocothemis servilia is another widespread dragonfly species in India, seen frequently perching on the low vegetation at temporary lakes and permanent ponds. This species also feeds only on the live and predominantly flying insects like adults of Diptera, Ephemeroptera, Neuroptera with smaller Lepidopterans as well as damselflies (Mitra, 2007). It showed two peaks one during May-July and second during October to January as is also observed by Miller (2007) and Mitra (2007).

Ischnura senegalensis – Prefers stagnant or slow moving water and is absent in the intact forests (Clausnitzer 2006). The canal systems of the reservoirs produce slow moving water system increasing the abundance of this species. At the two reservoirs, TIR and WIR, where because of Narmada inundation the slow moving water system prevails for longer duration, probably this species is quite common.

Ictinogomphus rapax – A Gomphid known to be present all over the Oriental region with flight period all year round was the common species at TIR and WIR that have longer hydro period compared to JIR where it was uncommon. Although most of the Gomphids are known to breed in running water this species prefers stagnant water for breeding (Subramaniam, 2005).

Pantala flavescens – This migratory species is one of the best known and most-widely distributed libellulid, occurring in all the tropical and some temperate regions of the world (Askew, 1988; Silsby, 2001). They are found in large flocks swarming around the place where food is abundant. Sharma and Joshi (2007) found them to be the most dominant species at Dholbaha dam in Shivalik Punjab. This species breed in marshes and ponds and fly all throughout the year, but huge swarms can be seen just before and after monsoon (Subramaniam, 2005). The rating of this species as frequent at JIR may be attributed to the presence of *Rhyothemis variegate* a common species at JIR that exhibits similar flying behavior to that of *P. flavescens*, probably obstructing and pushing away the latter species.

Diplacodes trivialis **-** is another common species in India. It perches on low vegetation or on the ground and rarely flies over 1 m height and hence is called as the Ground skimmer (Miller, 2007). It breeds in the muddy puddles at the pond edges. It is observed all throughout the year as it has no specific flight period (Subramaniam, 2005). The differences in the rating of this species among the reservoirs can be mainly due to the availability of more muddy puddles around the larger WIR which are preferred by this species.

Crocothemis erythraea – is the species that perches on vegetation or ground in the vicinity of the water body. It is a low-land species preferring lower altitudes where the water is stagnant (Ott, 2007). In the lentic water bodies of the study, this species was rated as common at WIR while Frequent at TIR and JIR.

Diplacodes lefebvrii –The Black percher is a widespread species with range extending from Africa to Eurasia and is common in the Indian subcontinent. It prefers well vegetated temporary or seasonal freshwater habitats (Clausnitzer, 2005). JIR, though not temporary has comparatively shorter hydro period and water spread in the absence of

Narmada inundation hence probably this species was common at JIR while was uncommon at other two reservoirs.

Rhyothemis variegate –a prominent dragonfly of marshes, paddy fields and ponds is easily mistaken for a butterfly (Subramaniam, 2005). This species reported from many parts of India (Miller, 2007) is a weak flier and frequently perches on aquatic weeds. It is rarely seen away from water and flies all throughout the year near the perennial marshes (Subramaniam, 2005). It was common at JIR where emergent aquatic weeds are present towards dam side and uncommon at TIR and WIR where water is deeper towards dam side with less emergent vegetation for perching.

Bradinopyga geminate – This species was common at reservoirs with Narmada inundation. It usually perches on compound stone walls, boulders, *etc*. and easily amalgamates with surroundings because of its extremely varied colouration making it quite inconspicuous. The species is commonly found near rock pools and other similar small water collections (Subramaniam, 2005) which occurred due to seepage of water around the two reservoirs. It flies throughout the year and prefers sunlit time of the day (Miller, 2007).

Pseudagrion microcephalum – a species of both lentic as well as lotic habitats is generally found resting on the bushes in the water bodies or at the edges of the water body. Vegetation is very important for this species (Subramaniam, 2005) and the absence of vegetation for perching reduces its numbers. June to November is considered as its flight period when it is most active (Subramaniam, 2005). This species was frequent at WIR the larger reservoir with extensive canal system while uncommon at the other two reservoirs.

Onychargia sp. – Though a very widely distributed species, it is probably under-recorded in many areas. Where it occurs, it is common and is capable of surviving in secondary and disturbed habitats. It breeds in ponds and marshes with trees, and swamp forest

(IUCN, 2009). However, it was observed frequently at JIR and WIR while was rare at TIR.

Trithemis aurora – A frequent species at WIR while uncommon at TIR and JIR, is one of the common dragonflies of wetlands of India. The males usually perch on dry twigs, aquatic plants and over head cables. It breeds in streams, rivers, canals, ponds and tanks and flies all throughout the year (Subramaniam, 2005). In the present study it was mainly observed during September to December as is also reported by Kumar (1972).

Ischnura aurora – It is a widespread species found in plains as well as altitudes, and common among vegetation along the banks of ponds, rivers, canals and estuaries (Subramaniam, 2005). It preys on both the flying as well as settled prey like the Diptera and Epmeroptera (Mitra, 2007). In the present study its occurrence was low and varied at the three reservoirs as rare, common and uncommon.

Ceriagrion coromandelium –rated as frequent at JIR, the reservoir with reeds while uncommon at other two is reported to be common along the banks of ponds, rivers and canals and also found frequently far away from water bodies. It breeds in shallow water bodies with profuse growth of grass and other aquatic plants (Subramaniam, 2005). It perches on low vegetation (Miller, 2007) and makes periodic swift flights to prey on the small flying insects (Mitra, 2007). This species was reported to be one of the dominant species in the study by Sharma and Joshi (2007) at Dholbaha dam of Shivalik Punjab.

Sympetrum vulgatum - rated as frequent at JIR while uncommon at TIR and WIR, is basically a European species that has expanded its range in Asia. It breeds in standing water and hence probably was observed around the reservoirs.

Agriocnemis pygmaea –Though a common Indian species during October-January (Subramaniam, 2005), it was uncommon around all the three reservoirs. It is known to be present in diverse natural and manmade habitats. Its larvae commonly occur among the aquatic weeds and algae (IUCN, 2011) while adults perch among the vegetation and flies very close to the ground.

Trithemis kirbyi – Though this species has wide distribution and prefers freshwater like Streams, rivers and pools, woodland or bushes (IUCN, 2011), it was uncommon at all the three reservoirs.

Copera marginipes – The species with varied status as absent at WIR, rare at JIR and uncommon at TIR is known to inhabit ponds, puddles, canals and streams. It also flies very close to the ground and breeds in shallow water collections, such as rainwater puddles and backwaters of streams. August-November is considered as its flight period (Subramaniam, 2005). In present study also it was observed from September to November.

In a habitat the core species show fewer variations in flight period as compared to the edge species. The climatic variations are also more pronounced at the edge of habitats (Purse and Thompson, 2003). Distribution of different species of Odonates is not recorded for Gujarat hence which species is core species and which species is edge species cannot be decided for the semi arid zone of Gujarat with reference to varied flight period. The common species are usually found in larger numbers as compared to the rare species (Shelton and Edward, 1983; Kandibane *et al.*, 2005). The common species have the ability to survive in the existing environmental conditions and are observed all through the year. This was found to be true in the present study too, where the rare species disappeared with the change in the season but common did not.

Jaccard's Similarity Index (J)

The higher annual Jaccard's similarity index suggests the overall resemblance of the habitats around the three reservoirs in the semi arid zone of Gujarat which are hardly 25 to 50 Kms. away from each other. Dispersal of flying species aided by wind cannot be ruled out when the macroclimatic conditions are same. Annual scenario showed more resemblance between TIR and JIR with highest similarity in post-monsoon which is the flight period for many Odonates. The seasonal species composition differed leading to low similarity index. Dragonflies react quickly to the disturbances that are caused due to human pressures which forces them to move to better location (Bried, 2005). In the present study, the influence of disturbance caused by the human movements is seen at TIR which probably disturbed the colonization of the dragonflies forcing them to disperse during different seasons of the year resulting in low number and hence lower similarity. Overall higher numbers of species were observed during summer and post-monsoon at TIR while at other two reservoirs the differences were not so significant, the results of undisturbed and stable habitat over all the seasons.

Species Richness

The highest annual odonate mean species richness at JIR can be accredited to the maximum species present around the reservoir which offered the most suitable perches on the edges of the water body. In addition, a cluster of trees is also present on the earthen dam itself with the scrub vegetation on both the slopes. At WIR the grasses growing in the marshy areas created due to seepage from the reservoir provided good perching posts increasing odonate species richness. The effect of larger size also cannot be ruled out. The Ground Skimmer (*D. trivialis*), Ditch Jewel (B. *contaminate*) and Ruddy Marsh skimmer (*C. servilia*) preferring the Ground level were regularly present here. The species richness at both these reservoirs was mainly due to the presence of the species that prefer stagnant water for breeding. At TIR, the species richness was comparatively low due to human disturbances caused by domestic activities and the presence of the scrub a little far from the dam. Though urbanization does not affect the dragonfly diversity (Lubertazzi and Ginsberg, 2010) human presence has been reported to disturb Odonates (Bried, 2005; Maiolini and Carolli, 2009) as they react quickly by appearing or disappearing from the habitat.

Several species prefer moving in sunlight and during summer there is good sunlight which encourages them to come out and fly. Being Poikilothermic and of tropical origin (Krishnaraj and Pritchard, 1995; Sternberg, 1994), the distribution, seasonality and inter-habitat variations of Odonates are strongly restricted by climatic factors, especially temperature (May, 1978). Ubukata (1973) and Purse and Thompson (2003) have reported the odonate emergence to be facilitated by high temperature. Odonates are also reported to postpone their emergence in the absence of the suitable climatic conditions (Purse and Thompson, 2003). Hence, the higher species richness during summer is due to larval emergence into imago as well as the higher temperature that facilitate the suitable conditions for the adults to forage.

Monsoon too is a favourable season for odonates as they exhibited good species richness around the three reservoirs. During monsoon many species perform breeding activities. The basic requirement for this group of insects is the availability of water for egg laying which is easily available in monsoon. Post-monsoon is also a suitable period for Odonates as water is still plenty around, which also facilitates their reproduction. During this season places for perching are available as vegetation flourishes and clouds disperse bringing in sunshine. For Odonates, although the potential emergence pattern is determined by the mode of seasonal regulation, the actual pattern depends on proximate climatic factor like temperature (Corbet, 1957; Lutz, 1968; Gribbin and Thompson, 1990). Though the temperature in post-monsoon is comparatively high the other proximate factors like adequate water sources, emergence of macrophytes and availability of food encourage the species to reproduce successfully. During winter the temperature drops creating somewhat unfavourable conditions for both the dragonflies and the damselflies when they are observed only during the afternoon hours when the sun is high. In winter the lower temperatures were more influential than the water availability accompanied by the death of the macrophytes which has been reported to be unsuitable for Odonates (Hawking and New, 2002).

Temperature has been implicated in determining the structure of aquatic communities (Carpenter *et al.,* 1992; Heino, 2002; Burgmer *et al.,* 2007). Mesocosm experiments have suggested that a 3°C increase in water temperature would have negligible impacts on the structure of aquatic macro invertebrate communities (Feuchtmayr *et al.* 2007). Although natural Odonate communities appear to exhibit high rates of turnover in response to changing season, changing climate with change in temperature does not influence the high rate of odonate turnover (Flenner and Sahlén, 2008; Hassal and Thompson, 2008). Hence comparatively high species richness of Odonates was found during summer as well as other parts of the year in the subtropical semi arid zone of Gujarat where the temperature are comparatively high irrespective of dry or wet season.

As none of the three reservoir dried off completely during study, water was available all throughout the year. Hence, good species richness of Odonates was observed all round the year except winter.

Climatic and habitat stability are known to increase the level of endemism (Fjeldså *et al*., 1997). Many researchers have reported rainfall to be a precursor for increased insect activities (Anu *et al*., 2009). However, in the present study, the species richness of Odonata was not influenced by rainfall. As water is the basic requirement for the nymphal odonates, these are mostly observed in the areas with adequate water and hence, may not solely depend on rainfall for their development. However, the species richness was reported to be higher during these periods, *i.e.* Monsoon and post-monsoon and also in summer which is considered the flight period of most of the Odonates.

As discussed earlier, the comparatively low species richness at TIR in all seasons may be attributed to the human disturbance along with the sparse vegetation present a little far from the earthen dam. Here also the highest species richness was recorded during post-monsoon. The comparative low species richness in summer as well as monsoon was mainly due to the absence of most of the damselflies which ultimately decreased the species richness.

At JIR, the species richness was recorded to be high all throughout the year except in winter when it was comparatively low. This can be mainly attributed to water availability, presence of bushes/vegetation for perching and relatively undisturbed habitat. Hence it can be said that the change in season is minor factor if other conditions are favourable. The species richness was higher at WIR during the two seasons when the temperature and other climatic factors are suitable for this group of insects.

Density

Even though annually JIR supported maximum species, it did not support maximum density of Odonates which was noted at WIR-the probable influence of the size. However, with reference to other fauna it has been reported that larger the area more is the possibility of the dispersion leading to decline in density (Smallwood and Schonewald, 1996; Gaston and Blackburn, 2000). The density at TIR and JIR did not show much difference. Clausnitzer (2003) has reported an increase in the dragonfly species with increase in light penetration and the river width. WIR being larger reservoir the depth is greater and being located in semi arid zone light availability is high with greater penetration due to submergent vegetation. This probably increased the breeding rate leading to higher density of Odonates. Annual Density of Odonates was mainly influenced by the presence of Ditch Jewel, Long legged Marsh Glider (*T. pallidinervis*) and Wandering Glider (*P. flavescens*) at TIR and WIR, while Common Picture wing (*R. variegate*) and Ditch Jewel at JIR.

The seasonal density also suggests that post-monsoon is the most favourable period for Odonates. This season provides most suitable climatic conditions for dragonflies and damselflies. Ditch Jewel and Ground Skimmer contributed to the higher density in post-monsoon at WIR and TIR, while Wandering Glider was an additional species at TIR. The latter along with Common picture wing contributed to the density at JIR. The higher population of odonates recorded during this season can be accredited to the presence of more exposed macrophytes that emerged out of the water providing perching posts over clear water (to guard the eggs and larvae). Samways and Steytler (1996) have reported that shade and exposed macrophytes are important environmental variables determining Odonata distribution.

The seasonal variations at TIR showed very low density in winter as none of the species were present in higher numbers in contrast to good numbers of Ruddy Marsh skimmer (*C. servilia*) and Ditch jewel at JIR and Ditch Jewel, Long legged Marsh Glider and Wandering Glider at WIR in early as well as late winter (beginning of December and February end). The sensitivity to physical habitat quality makes Odonates useful indicators of habitat quality above as well as below the water surface. However, the water quality and aquatic habitat morphology, such as bottom substrate and vegetation structure, are critical to dragonfly larvae while the adult habitat selection is strongly dependent on vegetation structure, including degrees of shading (Clausnitzer, 2006). Hence, any change in the habitat influences the dragonfly population and their number declines. This was found to be evident at TIR where during 2010 -11 winter large number of *Acacia* and *Prosopis* species were removed for restoration of dam leading to change in the habitat that in turn reduced the dragonfly density. However, relatively higher density present at JIR and WIR during winter can be indication of the low level of changes present around the reservoirs surrounded by higher agricultural matrix.

Although there was good variation in the species richness in summer and monsoon at TIR and JIR, the variations in the density were not significant. The density at all the three reservoirs showed a drastic drop by the end of summer and in the early monsoon *i.e.* in late May and Early June. This may be principally attributed to the hot weather with decline in the availability of water as well as disturbance due to fishing activities especially at WIR. Further, as is said by Maiolini and Carolli (2009), human disturbances trigger the dispersal of very sensitive Odonate groups. At TIR also the fishing activities are carried out, but not as extensive as WIR. Due to Narmada inundation the water spread was also larger which probably facilitated the activities of the Odonates at TIR hence they were reported in higher number as compared to WIR. At JIR as there is no fishing activity as well as the water was adequate in the summers of the study period the density was higher.

Common species dominate in disturbed habitats while species with tight habitat preferences and regional importance disappear with increasing habitat disturbances (Clausnitzer, 2003) as is also noted for TIR where *Brachythemis contaminate* was the main density determining species. Further, as excess of water is not favoured by odonates (Subramaniam, 2005) the input of rain water decreased the odonate density in monsoon. Among the three reservoirs the density of Odonates at Wadhwana was always high compared to other two reservoirs in all seasons, except summer when the conditions were more favourable at JIR with water as well as vegetation on the earthen dam providing perches.

Shannon Weiner Species Diversity Index (H')

Highest annual H' reported at WIR suggests that the odonates are more established here compared to other two reservoirs. Lowest H' at TIR can be attributed, firstly to the higher numbers of generalist species, and secondly to the overall low number of species present. Diversity index depends on the number of species present in addition to the number of individual of each species.

Diversity index also indicated that the post-monsoon is the favourable season due to presence of higher numbers of species with moderate population. In winter the lowest density was due to overall low number of species. However, the moderate H' reported for this group of insects suggests the population to be stable in the semi arid zone of Gujarat. The non-significant seasonal differences in H' clearly shows that the Odonates were never extreme in their numbers and their population was regulated by one or the other environmental factors. In the present study, at all the three reservoirs the low variation in the seasonal diversity index suggests that the odonate community in the area is reasonably good. Absence of the major differences in H' among the reservoirs clearly suggests that all three reservoirs have equally well suited habitats for this group of flying insects.

Evenness (E)

Evenness at the three reservoirs did not show much of the variations in the annual scenario with almost high evenness recorded at the three reservoirs. The high evenness indicates the uniformity of the community. However TIR had the most even distribution of the species.

Heterogeneity is known to be higher in a community when there are more species and also when the species are equally abundant (Krebs, 1985). In the present study the numbers of species were high at all three reservoirs, but many species were found to be rare and hence the variation in the evenness was recorded. As far as water birds are concern Deshkar (2008) reported that low species richness leads to high evenness, while the high species richness results in low evenness. This was not found to be completely true for this group of organisms as both species richness and evenness were high during post-monsoon while, in winter the low species richness at TIR resulted in highest Evenness.

However, at JIR the evenness was more or less same in all the seasons except winter when it was lowest. The low number of species that also unevenly distributed with some species with very high numbers while others observed in ones and twos resulted in the low winter evenness. At WIR the evenness was found to be high when more number of species was present *i.e.* in monsoon and post-monsoon, while the lowest evenness in summer mainly due to the presence of exceedingly high numbers of *Trithemis pallidinervis* and *Brachythemis contaminate*. In winter too, the higher number of some species and absence of the other led to low evenness.

Percentage occurrence

Families belonging to both the sub-orders Anisoptera and Zygoptera of order Odonata are considered together. Highest number of Odonate species belonging to family Libellulidae (Anisoptera – Dragonflies), with widespread distribution (Subramaniam, 2005; 2009) led to its higher percentage occurrence. Most of the species belonging to this family were common and hence higher in numbers. The other family with moderate percentage occurrence is the Coenagrionidae (Zygoptera –Damselflies) which is the largest family of the damselflies. Although Gomphidae (Anisoptera – Dragonflies) was represented by only two species it had higher percentage occurrence due to the commonness of *Ictinogomphus rapax,* the species that was observed many times at all the reservoirs. Other families had low percentage occurrence or were even absent completely at one of the three reservoirs. Lestidae (Zygoptera –Damselflies) was present at all the reservoirs but all three species of genus *Lestes* were observed rarely and hence did not contribute much to the total odonate population. A single species *Copera marginipes contributed* to higher percentage occurrence of family Platycnemididae (Zygoptera –Damselflies) at TIR. Families Cordulegasteridae and Aeshnidae (Anisoptera – Dragonflies) as well as Protoneuridae (Zygoptera –Damselflies) could not find preferable niche at the reservoirs and hence were observed during their exploratory visits only, leading to their low percentage occurrence.

The seasonal scenario also showed Libellulidae to be the most dominant family with highest percentage occurrence due to their round the year presence along with their higher density during some part of the year. Coenagrionidae and Gomphidae were also present all throughout the year and hence had higher percentage occurrence. In case of Gomphidae, *Ictinogomphus rapax* was present in all the seasons of the year with good percentage occurrence. Libellulidae and Coenagrionidae were represented by the generalist species that are active all throughout the year while other specialist were active in different seasons of the year resulting in the perennial presence of this family. However, the species present all throughout the year were *Brachythemis contaminate, Trithemis pallidinervis* and *Crocothemis servilia* of family Libellulidae *at WIR, Pantala flavasens, Brachythemis contaminate and Trithemis pallidinervis at TIR* and *Rhyothemis variegate* and *Brachythemis contaminate* at JIR. Many authors have reported Libellulidae to be the dominant family in terms of abundance at different places in India as well as outside India (Asahina, 1993; Hamalainen, 1994; Gupta *et al.,* 1995; Norma-Rashid, 1995; Norma- Rashid *et al.*, 1996; Kumar and Mitra, 1998; Smolka *et al.*, 1999; Norma- Rashid *et al*., 2001; Prasad, 2002; Kumar, 2002; Vashishth *et al*., 2002; Kandibane *et al*. 2005; Emiliyamma, 2005; Emiliyamma *et al*., 2005, Sharma and Joshi, 2007, Kalkman *et al*., 2008; Subramaniam *et al*., 2008; Arulprakash and Gunathilagaraj, 2010) as it is widespread locally as well as globally (Norma- Rashid *et al*., 2001).

Family Coenagrionidae present in all the seasons was not common in summer, hence it could be said that the dry hot summer is unfavourable for these weak fliers. Coenagrionidae had highest percentage occurrence during winter at all the reservoirs. This was opposing to Gomphidae and Libellulidae which had higher percentage occurrence during post-monsoon and summer respectively. The higher percentage of Coenagrionidae in winter may be mainly attributed to the flight period of many species of this family from September to January (Subramaniam, 2005). This family also had good percentage occurrence in post-monsoon. As the percentage occurrence is a comparative index where the higher percentage occurrence of one family affects the percentage occurrence of the other, it ultimately decreases the percentage of others (Hurd *et al*.,1971). In the present study also it was noted that the increase in the percentage occurrence of Coenagrionidae influenced the percentage occurrence of Libellulidae. All other families were either absent during some seasons of the year or were rarely sighted and hence did not affect the percentage occurrence of the families Libellulidae and Coenagrionidae.

Lestidae is a family of damselflies that normally prefers temporary pools hence its adults are found in the vicinity of the water bodies. Although the flight period of this family is recorded to be June to September in the Peninsular India (Subramaniam, 2005) these were not recorded in monsoon and were most common during summer and showed occasional presence in post-monsoon at TIR while in winter at JIR. This indicates that some species of Lestids have wider and different flight period in semi arid zone of Gujarat, India.

Protoneuridae was a rare family found at WIR only during summer, and hence did not affect the overall percentage occurrence. Similarly Platycnemididae had a single species but was observed all throughout the year except winter at TIR. Its higher percentage occurrence during monsoon and post-monsoon was due to its flight period from August to November (Subramanaim, 2005). However, its appearance in summer at TIR and single appearance at JIR during winter may be exploratory.

As for annual percentage occurrence, *Ictinogomphus rapax* increased the seasonal percentage occurrence of Gomphidae in all the seasons at the three reservoirs. Hence it can be said that the species present all throughout the year are more important for the percentage occurrence of a family. The flight period of Cordulegasteridae only from April to September (Subramaniam, 2005) resulted in their lower percentage occurrence.

Coenagrionidae and Libellulidae are the two dominant families of the study. Libellulidae was more dominant in summer when other families had low percentage occurrence.

However in post-monsoon and winter the dominance of Libellulidae was shared by Coenagrionidae.

Most of the odonate species have their flight period during monsoon and post-monsoon (Subramaniam, 2005), but in the present study all the families recorded at WIR and TIR were present during summer. This can be in response to the extended hydro period due to Narmada inundation in the semi-arid zone of Central Gujarat, India. On the contrary, winter which is considered to be the unfavourable season for the Odonates recorded presence of all the five families at JIR. This can be primarily due to the presence of species belonging to the three common families Coenagrionidae, Gomphidae and Libellulidae and the accidental presence of Lestidae as well as Platycnemididae during winter.

Importance of Odonates as Indicators of Environmental Health

Of all the habitats being affected by land conversions, wetlands are among the most impacted ones (Reece and Mcintyre, 2009). They are usually poorly protected, and their important biological resources are easily lost through clearance and overuse (Clausnitzer, 2004). These are one of the major ecosystems that support the odonate density and diversity as many of the odonates prefer standing water which are present at wetlands. Hence to save the extinction of the several Odonate species supported by these ecosystems, wetlands need to be conserved. Major threats to wetlands are excessive exploitation, changes in water quality due to industrial effluent, agricultural pesticides, siltation and the introduction of exotic species. An immediate cessation of these activities is need of the time for preventing the habitat destruction of the Odonate species. Wetlands are crucial resources, and as their degradation continues to occur as a result of indirect and direct human activities, it is vital to elucidate the proximal effects of land use on odonate community structure (Reece and Mcintyre, 2009).

There have been numerous recent studies from around the world that have documented that odonates respond to anthropogenic activities and thus may serve as useful indicators of habitat quality in terms of species occurrence (Samways and Steytler, 1996; Kadoya *et al*., 2008), diversity (Rith-Najarian, 1998; Sahlén and Ekestubbe, 2001; Clausnitzer, 2003; Sahlén, 2006; Suhling *et al*., 2006), distribution (Flenner and Sahlén, 2008), morphology (Taylor and Merriam, 1995; Hardersen and Frampton, 1999), and dispersal (Jonsen and Taylor, 2000).

Different ecological requirements are linked to different dispersal capacities. Species with narrow niches often disperse poorly, while pioneers of temporal habitats (often created by disturbance) are excellent colonizers. Odonates in particular are good aerial species for evaluating habitat connectivity (Clausnitzer *et al.*, 2009). In summary, Odonata are an easy-to-study group and are useful for monitoring the overall biodiversity of aquatic habitats and have been identified as good indicators of environmental health (Samways and Steytler, 1996; Corbet, 1999; Sahlén and Ekestubbe, 2001; Clausnitzer, 2003; Suhling *et al*., 2006; Kalkman *et al*., 2008). According to Clausnitzer *et al.* (2009), most of the threatened species are clustered in the Indo-Malayan and Australian realms and hence they need to be documented at least before they get extinct. Conservation strategy needs to be developed and implemented to stop further deterioration of the Odonate species. The species inhabiting lotic waters are at greater risk than those in lentic waters, may be partly due to lentic habitats being less predictable in space and time. Species in lentic systems tend to be more generalised and have a higher dispersal capacity (Corbet, 1999), resulting in larger ranges and wider ecological preferences, and therefore lower extinction risk (Clausnitzer and Jodicke, 2004; Hof *et al*., 2005).

Odonates are currently the only insect group for which a representative global assessment of conservation status with reference to taxonomy and distribution has been completed and analysed (Clausnitzer *et al*., 2009). Hence, looking at its importance in the global assessment, for planning the conservation strategy of the wetlands they first need to be documented and later the indicator species may be identified.

Apart from butterflies, probably no other group of insects has received so much attention from the general public and has many organizations devoted to its study (Kalkman *et al.*, 2008). If conservation measures are to succeed then preparation of baseline inventory has been stressed with regular monitoring of changes in their species richness and abundance to assess the ecological health of the area (Chelmick *et al.*, 1980; Clark and Samways, 1994). Hence the present study is expected to provide information regarding status of Odonates around three reservoirs in the semi-arid zone of Gujarat, India.

HEMIPTERAN DIVERSITY AROUND WETLANDS

Introduction

Hemiptera is an order of exopterygots that shows incomplete metamorphosis (hemimetabolous) and basically includes True Bugs, Cicadas, Hoppers, Aphids and allies. Literally Hemiptera means the insects with half wings. According to the earlier classification, Hemiptera was broadly classified into two sub-orders *i. e*. Homoptera and Heteroptera. However, recently the sub-order Homoptera is divided into three sub-orders. These are Auchenorrhyncha (Free-living Hemipterans) that includes Cicadas, Treehoppers, Leaf hoppers and planthoppers; Sternorrhyncha (Plant-parasitic Hemipterans) comprising of Aphids, white flies and scale insects; and Coleorrhyncha comprising a single family not recorded from India. These three sub-orders have membranous forewings while Heteroptera have forewings with hardened base called Hemelytra. Heteropterans are the true bugs which have adapted to wide range of habitats and hence may be aquatic, semi-aquatic or terrestrial in habits. The order Hemiptera consists of both economically useful as well as economically harmful insects. The predatory bugs act as the bio-control agents and the species like lac insect produces lac that is economically important. Some hemipterans like aphids and scale insects are the pest damaging several crops. Aquatic or terrestrial, hemipterans perform a strong role in the food chain. Hence preparing inventory of Hemiptera of the different ecosystems becomes a prerequisite.

Some Auchenorrhyncha, free living bugs, produce sound for the communication which is audible to the human ear. Most of them are the plant suckers feeding on the juices produced by the different parts of the plant ranging from the leaves, twigs, branches and/or trunk to the roots of the host. These are strong jumpers with fast aerodynamic movements that help in escaping from predators. Sternorrhyncha includes the bugs that are mainly plant parasites. Aphids, White flies, Scale insects and Mealybug that represents this sub-order are the major pest of ornamental as well as agricultural crops. Hence, the original Homopterans which are divided into three suborders are the plant feeders in comparison to Heteropteran bugs which exhibit varied feeding habits. Phytophagous hemipterans are thus important and conspicuous components of many herbivore insect communities (Kennedy and Southwood, 1984; Majer *et al*., 1997; Hill *et al*., 1998).

Heteroptera - the true bugs include more than 25,000 species of terrestrial and aquatic bugs. Terrestrial species are mostly associated with plants that pierce tissues and feed on their juices (Knight, 1941; McGavin, 1992), many are entomophagous (Hassanzadeh *et al*., 2009) while many are serious plant pests (Safavi, 1973). Many species of bugs catch other insects and hence are beneficial to agricultural practices too (Linnavuori and Hosseini, 2000; Das and Gupta, 2010). Aquatic Hemipterans are important food sources, for fish, amphibians, waterfowls and other animals (Clark 1992), as well as bio-indicators and predators (Das and Gupta, 2010). Hence, they have an intermediate position in the food chain (Runck and Blinn, 1994). Certain hemipteran families have potential to be used as the bio-control agent for mosquito larvae too (Saha *et al*., 2007). Hence, Hemiptera is a versatile group known to adapt well in a wide variety of environments and their presence around water reservoirs in not surprising. The true bugs have been intensively studied mainly in aquatic habitats (Polhemus and Polhemus, 2008), and agricultural ecosystems (Fauvel, 1999), due to their important functional roles as predators and herbivores and also as indicator groups for overall arthropod species richness within a habitat as well (Duelli and Obrist, 1998). In the present study also this group of arthropods is considered with reference to its richness in the land around wetland.

Results

In the present study, total 19 species of hemipterans belonging to 14 families were observed around the three reservoirs (Annexure 2). Of the 14 families, 3 families (Membracidae, Cicadellidae, Lophopidae) belong to sub-order Auchenorrhyncha, 4 families (Aphidae, Aleyrodidae, Coccidae, Pseudococcidae) to sub-order Sternorrhyncha and 7 families (Pyrrhocoridae, Pentatomidae, Lygaenidae, Reduviidae, Gerridae, Belastomidae and Nepidae) to sub-order Heteroptera. The last three families of Heteroptera include aquatic bugs.

Highest 17 species of Hemiptera belonging to 12 families were observed at WIR, 15 species belonging to 11 families at JIR and 12 species representing 9 families at TIR. Nine families (Membracidae, Lophopidae, Aphidae, Aleyrodidae, Coccidae, Pyrrhocoridae, Pentatomidae, Lygaenidae and Gerridae) recorded at TIR were common around all the three reservoirs while family Cicadellidae and Pseudococcidae were recorded only around JIR and families Reduviidae, Belastomidae and Nepidae only around WIR. 3 species of the family Membracidae were present at all the three reservoirs along with Aphididae represented by two species and Pentatomidae by one, two and three species around TIR, JIR and WIR respectively. All other families were represented by a single representative each (Table 4.1, Figure 4.1). The most common hemipteran species encountered in the present study was Treehopper - *Oxyrhachis tarandus.* As study concentrates on terrestrial insects, density of Water strider (*Gerris* sp.) was not included in density calculations with White flies (*Bemisia tabaci*) which when occurred, occurred in thousands.

Abundance rating (Table 4.2, Figure 4.2,Table 4.8)

When all the hemipterans species are rated according to their encounter, no species was rated abundant at any of the three reservoirs. Two species, *Oxyrhachis tarandus* and *Bemisia tabaci* were common at TIR and WIR, while only the former at JIR. Two more hemipterans namely *Lygaeus sp.* and *Gerris sp.* were also common at WIR. 3 species each were frequent at TIR and JIR while only a single species at WIR. These include *Lygaeus sp., Gerris sp. and Oxyrhachis sp.1* at TIR, *Lygaeus sp., Bemisia tabacci and Oxyrhachis sp.2* at JIR and *Dysdercus cingulatus* around WIR. Of the 4 uncommon species at TIR and JIR, *Aphis gossypii* was *uncommon* at TIR while *A. nerii and D. cingulatus* at TIR as well as JIR. *Oxyrhachis sp.1* and *Aspongopus janus* were the uncommon species at JIR and WIR and *Oxyrhachis sp.2* at TIR and WIR. 3 species were rated as rare at TIR, 7 at JIR and 9 at WIR.

Jaccard's Similarity index (J) (Table 4.3)

The **annual** Jaccard's similarity index was maximum 0.8 for TIR and JIR, minimum 0.68 for JIR and WIR while 0.71 between TIR and WIR (Figure 4.3). The **seasonal** similarity index (Figure 4.4) showed lowest similarity 0.5 in summer between TIR and WIR when it was highest 0.64 between JIR and WIR, and 0.55 between TIR and JIR. In monsoon lowest similarity 0.42 was recorded between TIR and JIR, 0.46 between TIR and WIR and highest 0.54 between JIR and WIR. In post-monsoon highest similarity 0.64 was noted between TIR and JIR, lowest 0.38 between TIR and WIR while 0.57 between JIR and WIR. Highest similarities for all the habitats were recorded in winter. However, maximum similarity 0.85 was observed for TIR and WIR and lowest 0.69 for TIR and JIR. Similarity index between JIR and WIR was 0.71. Overall minimum seasonal fluctuations were reported in the similarity index between JIR and WIR and maximum between TIR and WIR.

Annual Differences in the mean Species Richness, Density, Shannon Weiner Diversity index (H') and Evenness (E) (Table 4.4, Figure 4.5)

On an average low mean **species richness** was observed for hemipterans. However, lowest mean species richness of 2.98 ± 0.31 species was recorded at TIR and highest 3.93 ± 0.27 species at WIR and 3.0 ± 0.3 species at JIR. The differences in the species richness were significant ($p < 0.05$, $F_{(2, 125)}$ 3.57). The highest mean **density** 17.59 ± 3.74

individuals/m^2 was recorded for WIR, while density at TIR and JIR were nearly same with 13.29 ± 3.78 individuals/m^2 and 13.15 ± 2.21 individuals/m^2 respectively. The differences in the density varied non-significantly ($P > 0.05$, $F_{(2, 125)}$ 0.55). Low values of the mean **Shannon Weiner diversity index (H')** and mean **Evenness (E)** for hemipterans at all the three reservoirs differed non-significantly ($P > 0.05$) with $F_{(2, 125)}$ 0.01 and $F_{(2, 125)}$ 0.22 respectively . Shannon Weiner diversity index were 0.45 ± 0.08, 0.46 ± 0.07 and 0.44 ± 0.06 for TIR, JIR and WIR respectively. Evenness was 0.35 for both TIR and WIR while 0.4 for JIR.

Seasonal Differences in the mean Species Richness, Density, Shannon Weiner Diversity index (H') and Evenness (E) (Table 4.5, Fig. 4.6)

Species Richness

Seasonal variations around each Reservoir

TIR – Lowest mean species richness of hemipterans was recorded in monsoon (1.8 ± 0.39 species) which increased gradually in post-monsoon (2.18 ± 0.48 species) reaching to highest 4.25 ± 0.43 species in winter and decreased to 3.42 ± 0.77 species in summer. The differences in species richness varied significantly ($p < 0.05$, $F_{(3.41)}$ 4.09) across the year in different seasons.

JIR - The mean species richness of the hemipterans around JIR was lowest (1.83 ± 0.42 species) in summer which increased gradually across the seasons with 2.63 ± 0.53 species in monsoon, 3.43 ± 0.87 species in post-monsoon and highest 4.27 ± 0.41 species in winter with significant seasonal variations at $p < 0.01$ ($F_{(3.34)}$ 4.64).

WIR – The mean species richness for WIR was more or less same during summer, monsoon and post-monsoon with 3.17 ± 0.49 species, 3.18 ± 0.42 species and 3.4 ± 0.45 species respectively. It increased to maximum 5.83 ± 0.34 species in winter. The differences varied highly significantly ($p < 0.001$) across the seasons with $F_{(3.41)}$ 9.51.

Differences among the reservoirs

When the seasonal differences in the mean species richness among the three habitats are considered, maximum species richness was observed in winter for all the three reservoirs. During this period it was nearly same at TIR and JIR while it was higher for WIR. The differences among the reservoirs varied at moderately significant level of 0.01 ($F_{(2,32)}$ 5.37). In summer high species richness was observed at TIR and WIR and low at JIR, while in monsoon the higher species richness was observed at WIR followed by JIR and TIR. WIR and JIR had almost same species richness during post-monsoon while TIR had minimum. No significant variations were observed during summer, monsoon and post-monsoon with $F_{(2,33)}$ 2.14, $F_{(2,26)}$ 2.66 and $F_{(2,25)}$ 1.67 respectively.

Density

Seasonal variations around each Reservoir

TIR – At TIR, highest mean density of hemipterans, 24.21 ± 11.98 individuals/m^2 was recorded in summer, while lowest 0.76 ± 0.38 individuals/m^2 during monsoon which increased in post-monsoon to 3.93 ± 1.4 individuals/m^2 and reached to 21.37 ± 5.79 individuals/m^2 in winter. However, the differences over the seasons varied non-significantly ($P > 0.05$, $F_{(3, 41)}$ 2.75).

JIR - The mean seasonal density at JIR was 9.51 ± 4.69 individuals /m^2 in summer which increased to 12.09 ± 4.94 individuals /m^2 in monsoon but decreased to 7.87 ± 2.02 individuals /m^2 in post-monsoon and again increased in winter to highest 21.25 ± 3.48 individuals /m^2. The seasonal variations were non-significant ($P > 0.05$, $F_{(3, 34)}$ 2.13).

WIR – Lowest density of hemipterans 6.33 ± 3.37 individuals /m^2 was recorded in summer at WIR which increased through the seasons to 7.8 ± 1.83 individuals /m^2 in monsoon, to 25.93 ± 13.46 individuals /m^2 in post-monsoon and highest 30.88 ± 5.59 individuals /m^2 in winter. The seasonal differences varied significantly ($p < 0.05$, $F_{(3.41)}$3.31).

Differences among the reservoirs

As noted for species richness higher mean density of hemipterans was also recorded during winter. However, the differences in density during winter varied non-significantly ($p > 0.05$, $F_{(2, 32)}$ 1.17) with highest density noted for WIR and low for both TIR and JIR. However, during summer lowest density was recorded at WIR closely followed by JIR and highest at TIR again with non-significant differences among the three habitats ($p > 0.05$, $F_{(2. 33)}$ 1.54). In monsoon very low density was recorded at TIR, while at JIR and WIR it was highest and moderate respectively. The differences among the three habitats surveyed were significant at $p < 0.05$ ($F_{(2,26)}$ 4.45). The lowest mean density of Hemipterans in post-monsoon was recorded at TIR followed by JIR and maximum at WIR with non-significant differences ($p > 0.05$, $F_{(2. 25)}$2.07).

Shannon Weiner Species Diversity Index (H')

On an average very low Shannon Weiner diversity Index (H') was recorded for this order of insects.

Seasonal variations around each Reservoir

TIR – For TIR, highest H' 0.71 ± 0.18 was recorded in winter, while lowest 0.09 ± 0.07 in monsoon. During summer and post-monsoon diversity index was 0.55 ± 0.17 and 0.39 ± 0.15 respectively. The seasonal differences were non-significant ($p > 0.05$, $F_{(3. 41)}$ 2.72).

JIR – For JIR, lowest H' 0.21 ± 0.1 was recorded in summer which increased gradually across the year to 0.36 ± 0.1 in monsoon, 0.54 ± 0.21 in post-monsoon and highest 0.74 ± 0.1 in winter. The differences in H' were significant ($p < 0.05$, $F_{(3,34)}$ 4.07).

WIR – Highest H' 0.79 ± 0.11 was recorded in winter for WIR. During rest of the year it was quite low with 0.3 ± 0.11 in summer, 0.25 ± 0.11 in monsoon and 0.37 ± 0.12 in post-monsoon. Seasonal variations were significant at $p < 0.01$ ($F_{(3,41)}$ 4.98).

Differences among the reservoirs

Non-significant ($p > 0.05$) differences were noted among three reservoirs in all the seasons. Maximum H' was noted for Winter at all the three reservoirs with minor differences among the three ($F_{(2,32)}$ 0.09). During summer highest H' was recorded for TIR with lower values for JIR and WIR ($F_{(2,33)}$ 1.7). In the following season - monsoon contrary to summer lowest H' was recorded at TIR while highest at JIR with $F_{(2,26)}$1.85 while in the next season post-monsoon TIR and WIR had almost same diversity index while the higher value was noted for JIR with $F_{(2,25)}$ 0.28.

Evenness (E)

Seasonal variations around each Reservoir

TIR – Low mean evenness was noted for TIR all throughout the year with minimum 0.13 ± 0.1 in monsoon which increased through 0.35 ± 0.13 in post-monsoon reaching to the maximum 0.49 ± 0.11 in winter and maintained at 0.4 ± 0.13 in summer. The seasonal variations were non-significant ($p > 0.05$, $F_{(3,41)}$ 1.64).

JIR – Minimum mean evenness 0.2 ± 0.09 was noted in summer at JIR which increased to 0.41 ± 0.11 in monsoon and was maintained at 0.4 ± 0.15 in post-monsoon and further increased to highest 0.62 ± 0.08 in winter. The seasonal variations were significant ($p < 0.05$, $F_{(3, 34)}$ 3.21).

WIR – Highest mean evenness of 0.53 ± 0.06 was recorded for WIR in winter. During rest of the year it was maintained at low value with 0.29 ± 0.08, 0.26 ± 0.11 and 0.33 ± 0.11 in summer, monsoon and post-monsoon respectively. The seasonal variations were non-significant ($p > 0.05$, $F_{(3,41)}$ 2.04).

Differences among the reservoirs

Non- significant ($p > 0.05$) differences in the mean evenness were noted in all the seasons among the reservoirs. In summer minimum evenness was observed at JIR and maximum at TIR, while evenness of hemipterans for WIR was moderate with $F_{(2,33)}$ 1.08. In monsoon opposing results to that of summer were noted with maximum mean

Evenness for JIR and minimum for TIR ($F_{(2,26)}$ 0.11). In the next season post-monsoon non-significant differences were observed in mean evenness at the three reservoirs with $F_{(2, 25)}$ 0.07. Maximum evenness for all the three reservoirs was noted in Winter, but among them maximum mean evenness was noted for JIR while non-significantly lower for TIR and WIR with $F_{(2, 32)}$ 0.54.

Percentage Occurrence

Annual – Annual Percentage occurrence clearly suggests that Membracidae is the most dominant family around all the three reservoirs **(Table 4.6, Figure 4.7).**

TIR – At TIR, nearly 39% of the hemipteran population was attributed to Membracidae consisting mainly of three species of Treehoppers. Aleyrodidae was the second most dominant family with 17.21 % occurrence contributed by a single species. Gerridae followed with 12.3% of the total population again contributed by a single species. Families Aphididae with 2 and Lygaeidae with one species, closely followed with 11.48% each of the total population. Other families also represented by single species each had lower percentage occurrence with 4.1% of Pyrrhocoridae, 2.46 % of Coccidae and 0.82% each of Lophopidae and Pentatomidae. 5 families (Cicadellidae, Pseudococcidae, Reduviidae, Belostomidae and Nepidae) of the total 14 families were absent around this reservoir.

JIR – At JIR also family Membracidae contributed to 43.64% of the total hemipteran population represented by three species. Other families with major contribution were Lygaeidae with 12.73% and Aleyroididae - the white flies with 10%, Aphididae and Pyrrhocoridae with 9.09% each and Pentatomidae with 7.27% of the total population. Gerridae which is considered to be the common aquatic species was rare at JIR and constituted only 2.73% of the total population. Cicadellidae, Lophopidae and Pseudococcidae contributed to only 0.91% each while family Reduviidae along with two aquatic families Belostomidae and Nepidae were absent here.

WIR - At WIR more families contributed to the hemipteran population with 28.4% Membracidae, 17.75% Gerridae, 14.79% Aleyrodidae, 12.43% Lygaeidae, 10.65% Pyrrocoridae and 7.1% Pentatomidae while Lophopidae, Aphididae and Coccidae constituted only 2.37% each. Reduviidae constituted 1.18% while Belostomidae and Nepidae only 0.59% each to the total hemipteran population. Two families, Cicadellidae and Pseudococcidae reported at JIR were absent here.

Differences among the reservoirs

The percentage occurrence suggests that Membracidae was the most dominating family around all the three reservoirs. The next dominant family was different at all the reservoirs with Aleyrodidae at TIR, Lygaeidae at JIR and Gerridae at WIR. Aphididae contributed minimally to percentage occurrence at WIR, Pyrrhocoridae and Pentatomidae at TIR, and Gerridae at JIR compared to other two reservoirs.

Seasonal Percentage Occurrence (Table 4.7, Figure 4.8)

The seasonal percentage occurrence showed that the members of families Membracidae and Lygaeidae were present around all the three reservoirs in all the seasons. Family Cicadellidae was represented only during post-monsoon at JIR. Family Lophopidae represented by a single species *Pyrilla perpusilla* occurred around the three reservoirs during monsoon, while only around WIR during post-monsoon. Family Aphididae was dominant during post-monsoon and winter at JIR and TIR while only in winter at WIR. Family Aleyrodidae occurred with higher percentage occurrence at all the three reservoirs all throughout the year except during summer at JIR. Coccidae was represented at all the reservoirs in winter, but was present at TIR and WIR in summer and only at WIR in post-monsoon. Family Pseudococcidae was present only during winter at JIR. Though families Pyrrhocoridae and Pentatomidae were represented all throughout the year at JIR and WIR, at TIR Pyrrhocoridae was present during summer and winter while Pentatomidae during winter. A single species of Reduviidae was recorded only at WIR during summer and monsoon. A single member of Gerridae was present all throughout the year around TIR and WIR while occurred only in summer and post-monsoon at JIR. Families Belostomidae and Nepidae were represented during different seasons only at WIR *i.e.* during monsoon and summer respectively.

Seasonal differences around reservoirs

As said for earlier chapters, for Hemiptera also percentage occurrence of different families in a particular season at each reservoir is taken into consideration.

Summer – During summer, only 6 families showed their presence at **TIR**. Of these, Membracidae contributed maximum 44.12 % which was followed by Aleyrodidae and Lygaedidae with 17.65 % each, Gerridae with 14.71%, while Cocidae and Pyrrhocoridae 2.94% each of the total population. At **JIR** only 5 families were noted during summer, again with Family Membracidae constituting 47.37% of the population, while Lygaeidae contributing 26.32%, Pyrrocoridae and Pentatomidae 10.53% each, while Gerridae 5.26% of the total hemipterans population. At **WIR** maximum nine families were represented in summer with families Membracidae, Aleyrodidae and Gerridae constituting 18.92% each of the total hemipterans population followed by families Pyrrocoridae and Lygaeidae with 16.22% each. However, families Coccidae, Pentatomidae, Reduviidae and Nepidae were observed only once during summer accounting to 2.7% each of the total population.

When comparison is made between the three habitats in summer it is observed that due to presence of other dominant groups at WIR Percentage occurrence of Membracidae was low compared to other two habitats. In summer at JIR Whiteflies (Aleyrodidae) and Scale insects (Coccidae) were totally absent while at TIR Red cotton bugs (Pyrrocoridae) were rarely sighted and Sting bugs (Pentatomidae) were completely absent. As observed for the annual percentage occurrence Gerridae was less frequent at JIR compared to other two reservoirs.

Monsoon- During monsoon only 5 families showed their presence at **TIR** with absence of Coccidae and Pyrrhocoridae and presence of family Lophopidae. During this season the most dominant family at TIR was Gerridae with 33.33% followed by Membracidae and Lygaeidae with 22.22% each and Aleyrodidae with 16.67% while Lophopidae constituted 5.56% of the total hemipterans. Other families recorded during the study were absent during monsoon at TIR. At **JIR** Membracidae was found to dominate Hemipterans with 36.36% of the total population. Lygaeidae also had higher 22.73% occurrence followed by Pentatomiodae (18.18%), Pyrrhocoridae and Aleyroridae 9.09% each and Lophopidae 4.55%. As observed for TIR, at **WIR** also during monsoon highest percentage was noted for Gerridae (28.57%) followed by Membracidae 22.86%, Lygaeidae 20%, Aleyrodidae 8.57%, and Lophopidae and Pyrrocoridae 5.71% each. Three families Pentatomidae, Reduviidae and Belostomidae constituted 2.86% each of the total hemipteran population in monsoon at WIR. When comparison is made between the three reservoirs in monsoon it is observed that Gerridae was absent at JIR while Pyrrhocoridae and Pentatomidae at TIR.

Post-monsoon – Membracidae was the most dominant family at all the three reservoirs during post-monsoon**.** At **TIR** Membracidae and Aphididae were the dominant families contributing 30% each, closely followed by Aleyrodiae with 25%, Lygaeidae with 10% and Gerridae with 5%. **JIR** had 39.13% of Membracids, while Aphids constituted 21.74%. Pyrrhocoridae, Lygaeidae and Gerridae each contributed 8.7% and Cicadellidae, Aleyrodidae and Pentatomidae each 4.35% of the total hemipterans population. At **WIR** also, during this season Membracidae accounted for 29.41% while Gerridae 20.59% and Aleyrodidae and Lygaeidae 14.7 % and 11.76% respectively. Pyrrocoridae contributed 8.82% of the total Hemipterans while Pentatomidae and Lophopidae 5.88% each. Coccidae constituted only 2.94% in post-monsoon at WIR. Amongst the three reservoirs Aphids were encountered in good numbers at TIR and JIR in post-monsoon whereas totally absent at WIR. A radical decrease in Gerridae was encountered at TIR compared to their presence in monsoon.

Winter – Highest percentage of Membracidae was recorded in winter for all the three reservoirs. The families that were absent during this season at all the three reservoirs were Cicadellidae, Lophopidae, Reduviidae, Belostomidae and Nepidae. At **TIR**, 8 families were represented rather than five compared to other seasons of the year. Of these, Membracidae constituted 46 % of the total Hemiptera**.** Aphididae constituted 16% and Aleyrodidae 14%. Other families constituting less than 10% of the hemipteran population include 8% of Pyrrhocoridae, 6% of Gerridae, 4% each of Coccidae and Lygaeidae, while 2% of Pentatomidae. At **JIR** also, total 8 families were present during winter with 48.89% of total hemipterans population contributed by Membracidae followed by 17.78% Aleyrodidae, 11.11% Aphididae and 8.89% Pyrrhocoridae. Coccidae and Lygaeidae accounted for 4.44% each while Pseudococcidae and Pentatomidae 2.22% each of the total hemipteran population. At **WIR** also maximum 34.92% occurrence was noted for Membracidae. Other families with significant percentage occurrence were Aleyrodidae with 15.87%, Pentatomidae with 12.7%, Pyrrhocoridae with 11.11%, Gerridae 9.52%, Aphididae and Lygaeidae 6.35% each and Coccidae with lowest 3%. Aphididae was present at WIR only during winter.

Table 4.1: Number of species belonging to various Hemipteran families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

Sr. No.	Families	TIR	JIR	WIR
1	**Membracidae (3)**	3	3	3
2	**Cicadellidae (1)**	0	1	0
3	**Lophopidae (1)**	1	1	1
4	**Aphididae (2)**	2	2	2
5	**Aleyrodidae (1)**	1	1	1
6	**Coccidea (1)**	1	1	1
7	**Pseudococcidae (1)**	0	1	0
8	**Pyrrhocoridae (1)**	1	1	1
9	**Pentatomidae (3)**	1	2	3
10	**Lygaeidae (1)**	1	1	1
11	**Reduviidae (1)**	0	0	1
12	**Gerridae (1)**	1	1	1
13	**Belostomidae (1)**	0	0	1
14	**Nepidae (1)**	0	0	1
	TOTAL (19)	**12**	**15**	**17**

Table 4.2: Abundance rating of Hemipteran species encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Abundant	Common	Frequent	Uncommon	Rare
TIR	0	2	3	4	3
JIR	0	1	3	4	7
WIR	0	4	1	3	9

Table 4.3: Annual and Seasonal Jaccard's Similarity Index (J) for Hemipterans between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Annual		Summer		Monsoon		Post-monsoon		Winter	
	TIR	JIR	TIR	JIR	TIR	JIR	TIR	JIR	TIR	JIR
WIR	0.71	0.68	0.5	0.64	0.46	0.54	0.38	0.57	0.85	0.71
JIR	0.8	-	0.55	-	0.42	-	0.64	-	0.69	-

Table 4.4: Annual Mean Species Richness, Mean Density, Mean Shannon Weiner Diversity Index (H') and Mean Evenness (E) of the Hemipterans at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Species Richness (*) $F_{(2,125)}$ 3.57	Density (ns) $F_{(2,125)}$ 0.55	Shannon Weiner index (ns) $F_{(2,125)}$ 0.01	Evenness (ns) $F_{(2,125)}$ 0.22
TIR	2.98 ± 0.31	13.29 ± 3.78	0.45 ± 0.08	0.35 ± 0.06
JIR	3.0 ± 0.3	13.15 ± 2.21	0.46 ± 0.07	0.4 ± 0.06
WIR	3.93 ± 0.27	17.59 ± 3.74	0.44 ± 0.06	0.35 ±0.05

Table 4.5: Seasonal variations in the Mean Species Richness, Mean Density, Mean Shannon Weiner Diversity Index (H') and Mean Evenness (E) of the Hemipterans at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

			Summer	Monsoon	Post monsoon	Winter
Species Richness		Among Reservoirs / Within Reservoirs	**(ns) $F_{(2,33)}$ 2.14**	**(ns) $F_{(2.26)}$ 2.66**	**(ns) $F_{(2,25)}$ 1.67**	**(**) $F_{(2,32)}$ 5.37**
	TIR	**(*) $F_{(3,41)}$ 4.09**	3.42 ± 0.77	1.8 ± 0.39	2.18 ± 0.48	4.25 ± 0.43
	JIR	**(**)$F_{(3,34)}$ 4.64**	1.83 ± 0.42	2.63 ± 0.53	3.43 ±0.87	4.27 ± 0.41
	WIR	**(***)$F_{(3,41)}$ 9.51**	3.17 ± 0.49	3.18 ± 0.42	3.4 ±0.45	5.83 ± 0.34
Density			**(ns) $F_{(2,33)}$ 1.54**	**(*)$F_{(2.26)}$ 4.45**	**(ns) $F_{(2.25)}$ 2.07**	**(ns) $F_{(2.32)}$ 1.17**
	TIR	**(ns) $F_{(3,41)}$ 2.75**	24.21 ± 11.98	0.76 ± 0.38	3.93 ± 1.4	21.37 ± 5.79
	JIR	**(ns) $F_{(3,34)}$ 2.13**	9.51 ± 4.69	12.09 ± 4.94	7.87 ± 2.02	21.25 ± 3.48
	WIR	**(*)$F_{(3,41)}$ 3.31**	6.33 ± 3.37	7.8 ± 1.83	25.93 ± 13.46	30.88 ± 5.59
Shannon Weiner index (H')			**(ns) $F_{(2,33)}$ 1.7**	**(ns) $F_{(2.26)}$ 1.85**	**(ns) $F_{(2.25)}$ 0.28**	**(ns) $F_{(2.32)}$ 0.09**
	TIR	**(ns) $F_{(3,41)}$ 2.72**	0.55 ± 0.17	0.09 ± 0.07	0.39 ± 0.15	0.71 ± 0.18
	JIR	**(*)$F_{(3,34)}$ 4.07**	0.21 ± 0.1	0.36 ± 0.1	0.54 ± 0.21	0.74 ± 0.1
	WIR	**(**)$F_{(3,41)}$ 4.98**	0.3 ± 0.11	0.25 ± 0.11	0.37 ± 0.12	0.79 ± 0.11
Evenness (E)			**(ns) $F_{(2,33)}$ 1.08**	**(ns) $F_{(2.26)}$ 0.11**	**(ns) $F_{(2.25)}$ 0.07**	**(ns) $F_{(2.32)}$ 0.54**
	TIR	**(ns) $F_{(3,41)}$ 1.64**	0.4 ± 0.13	0.13 ± 0.1	0.35 ± 0.13	0.49 ± 0.11
	JIR	**(*)$F_{(3,34)}$ 3.21**	0.2 ± 0.09	0.41 ± 0.11	0.4 ± 0.15	0.62 ± 0.08
	WIR	**(ns) $F_{(3,41)}$ 2.04**	0.29 ± 0.08	0.26 ± 0.11	0.33 ± 0.11	0.53 ± 0.06

Table 4.6: Annual Percentage Occurrence of the Hemipteran families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	TIR	JIR	WIR
Membracidae	39.34 %	43.64 %	28.4 %
Cicadellidae	0 %	0.91 %	0 %
Lophopidae	0.82 %	0.91 %	2.37 %
Aphididae	11.48 %	9.09 %	2.37 %
Aleyrodidae	17.21 %	10 %	14.79 %
Coccidea	2.46 %	1.82 %	2.37 %
Pseudococcidae	0 %	0.91 %	0 %
Pyrrhocoridae	4.1 %	9.09 %	10.65 %
Pentatomidae	0.82 %	7.27 %	7.1 %
Lygaeidae	11.48 %	12.73 %	12.43 %
Reduviidae	0 %	0 %	1.18 %
Gerridae	12.3 %	2.73 %	17.75 %
Belostomidae	0 %	0 %	0.59 %
Nepidae	0 %	0 %	0.59 %

TABLE 4.7: Seasonal Percentage Occurrence of the Hemipteran families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Summer			Monsoon			Post-monsoon			Winter		
	TIR	JIR	WIR	TIR	JIR	WIR	TIR	JIR	WIR	TIR	JIR	WIR
Membracidae	44.12	47.37	18.92	22.22	36.36	22.86	30	39.13	29.41	46	48.89	34.92
Cicadellidae	0	0	0	0	0	0	0	4.35	0	0	0	0
Lophopidae	0	0	0	5.56	4.55	5.71	0	0	5.88	0	0	0
Aphididae	0	0	0	0	0	0	30	21.74	0	16	11.11	6.35
Aleyrodidae	17.65	0	18.92	16.67	9.09	8.57	25	4.35	14.71	14	17.78	15.87
Coccidea	2.94	0	2.70	0	0	0	0	0	2.94	4	4.44	3.17
Pseudococcidae	0	0	0	0	0	0	0	0	0	0	2.22	0
Pyrrhocoridae	2.94	10.53	16.22	0	9.09	5.71	0	8.70	8.82	8	8.89	11.11
Pentatomidae	0	10.53	2.70	0	18.18	2.86	0	4.35	5.88	2	2.22	12.70
Lygaeidae	17.65	26.32	16.22	22.22	22.73	20.00	10	8.70	11.76	4	4.44	6.35
Reduviidae	0	0	2.70	0	0	2.86	0	0	0	0	0	0
Gerridae	14.71	5.26	18.92	33.33	0	28.57	5	8.70	20.59	6	0	9.52
Belostomidae	0	0	0	0	0	2.86	0	0	0	0	0	0
Nepidae	0	0	2.70	0	0	0	0	0	0	0	0	0

Table 4.8 - Abundance rating of the Hemipterans observed around three reservoirs

Sr. No.	Common name	Scientific name	TIR	JIR	WIR
	Sub-order : Auchenorrhyncha				
I	**Family: Membracidae**				
1	Two horned Treehopper	*Oxyrhachis tarandus*	C	C	C
2	One horned Treehopper	*Oxyrhachis sp.1*	F	U	U
3	Small Treehopper	*Oxyrhachis sp. 2*	U	F	U
II	**Family: Cicadellidae**				
4	Leaf hopper	*Idioscopus nifeosparsus*		R	
III	**Family: Lophopidae**				
5	Sugarcane Leaf-borer	*Pyrilla perpusilla*	R	R	R
	Sub-Order: Sternorrhyncha				
IV	**Family : Aphididae**				
6	Aphid	*Aphis gossypii*	U	R	R
7	Aphid	*Aphis nerii*	U	U	R
V	**Family: Aleyrodidae**				
8	White fly	*Bemisia tabacci*	C	F	C
VI	**Family: Coccidea**				
9	Scale Insect	*Coccus sp.*	R	R	R
VII	**Family: Pseudococcidae**				
10	Mealy bug	*Phenacoccus sp.*		R	
	Sub-order : Heteroptera				
VIII	**Family: Pyrrhocoridae**				
11	Red cotton bug	*Dysdercus cingulatus*	U	U	F
IX	**Family: Pentatomidae**				
12	Green stink bug	*Nezare viridula*	R	R	R
13	Stink bug	*Aspongus janus*		U	U
14	Brown stink bug	*Halymorpha halys*			R
X	**Family: Lygaeidae**				
15	Milkweed bug	*Lygaeus sp*	F	F	C
XI	**Family: Reduviidae**				
16	Assasin bug	*Oncocephalus sp.*			R
XII	**Family: Gerridae**				
17	Water stridder	*Gerris sp.*	F	R	C
XIII	**Family: Belostomidae**				
18	Gaint Waterbug	*Belatoma sp.*			R
XIV	**Family: Nepidae**				
19	Water scorpion	*Nepa sp.*			R

Figure 4.1: Number of Hemipteran species belonging to different families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

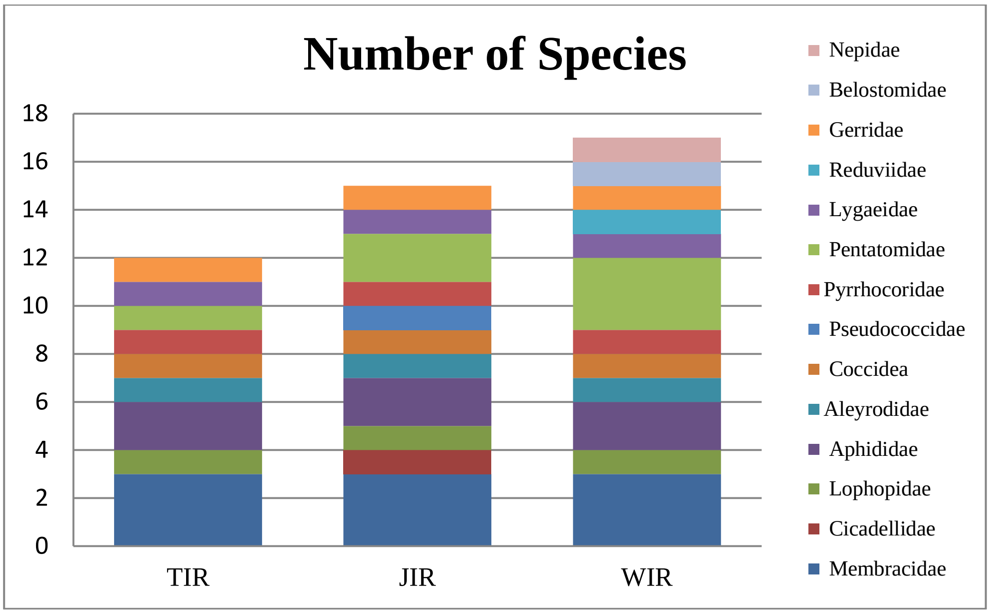


Figure 4.2: Abundance rating of the Hemipteran species encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

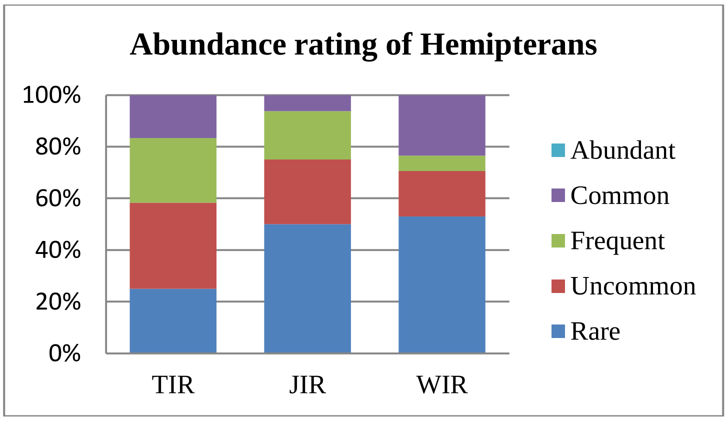


Figure 4.3: Annual Jaccard's similarity Index of Hemipterans between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

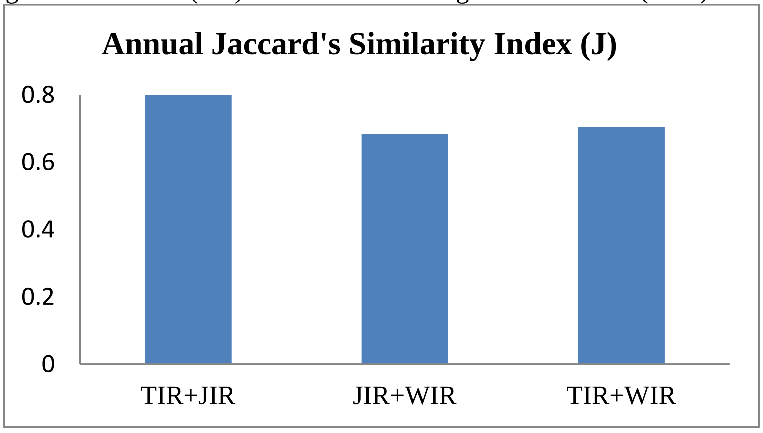


Figure 4.4: Seasonal Jaccard's similarity Index for the Hemipterans between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

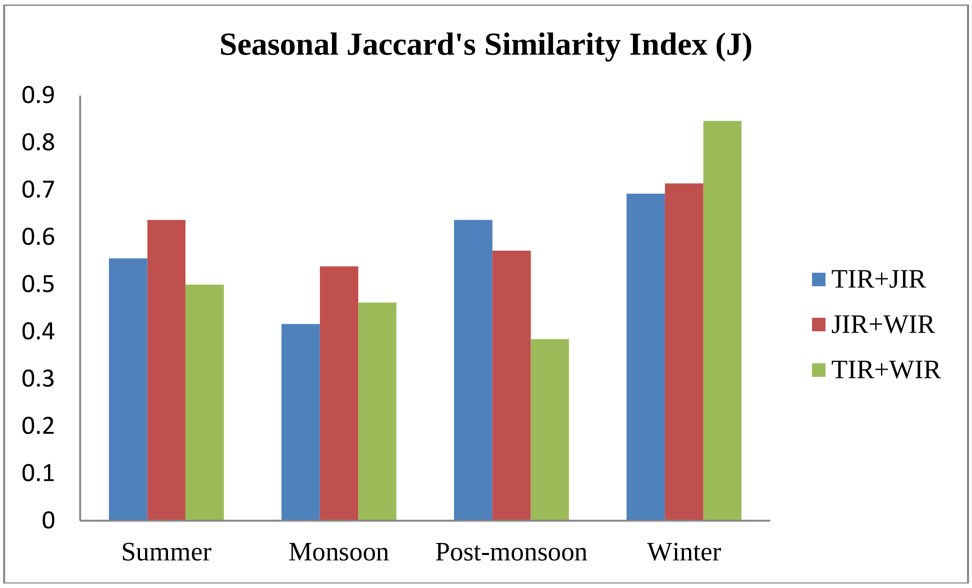
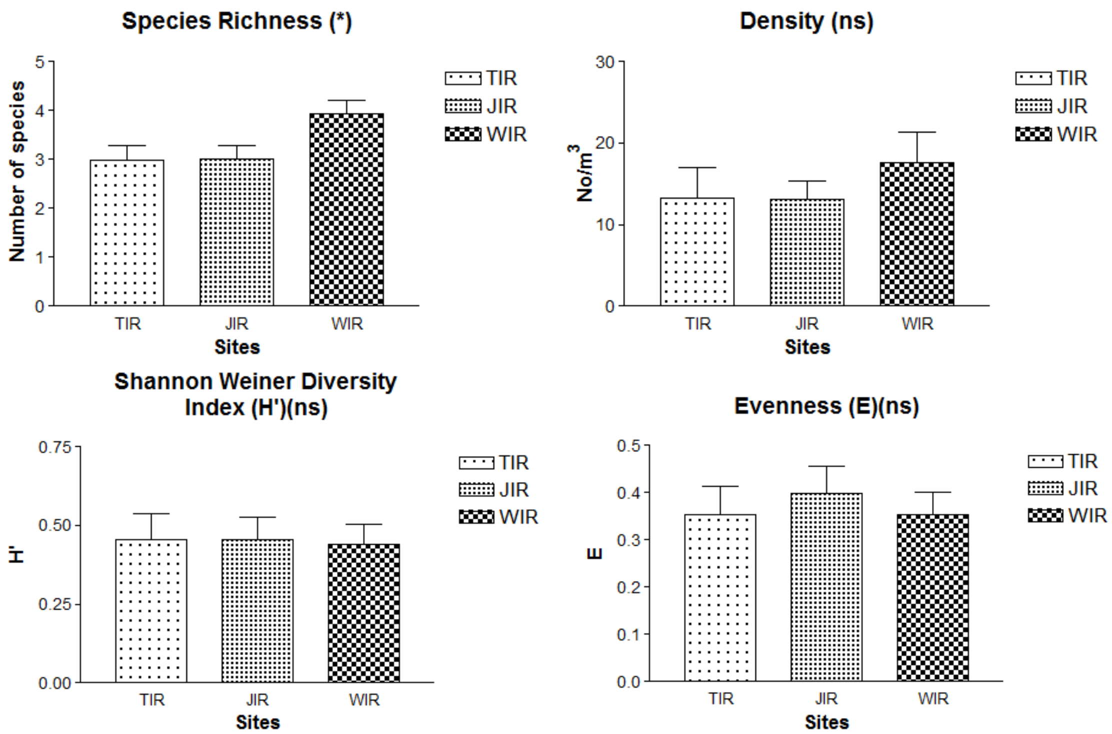
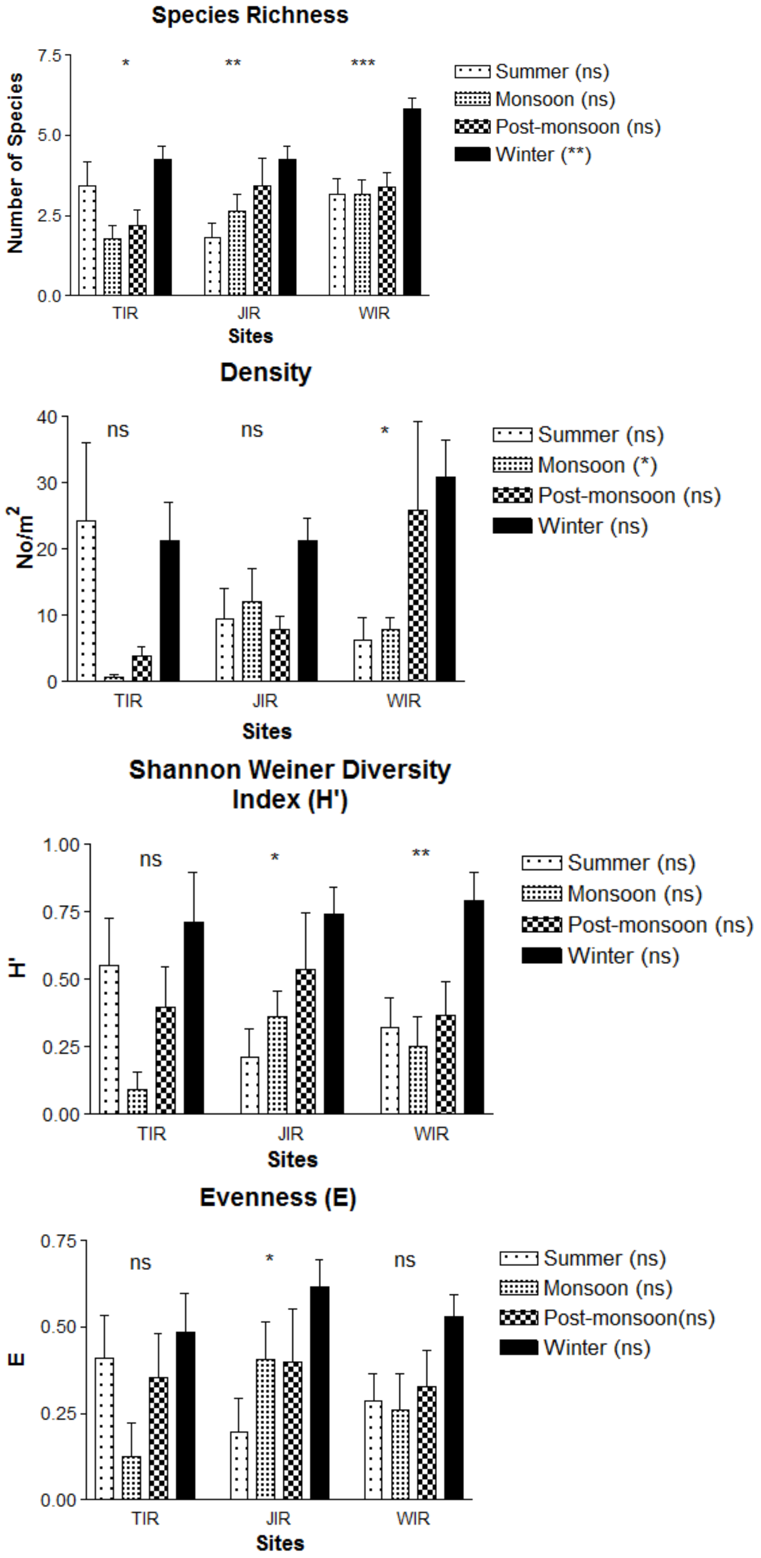


Figure 4.5 : Annual Mean Species Richness, Mean Density, Mean Shannon Weiner Diversity Index (H') and Mean Evenness (E) of Hemipterans at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

Figure 4.6 : Seasonal variations in the Mean Species Richness, Mean Density, Mean Shannon Weiner Diversity Index (H') and Mean Evenness (E) of Hemipterans at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

Figure 4.7: Annual Percentage Occurrence of the fourteen Hemipteran families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

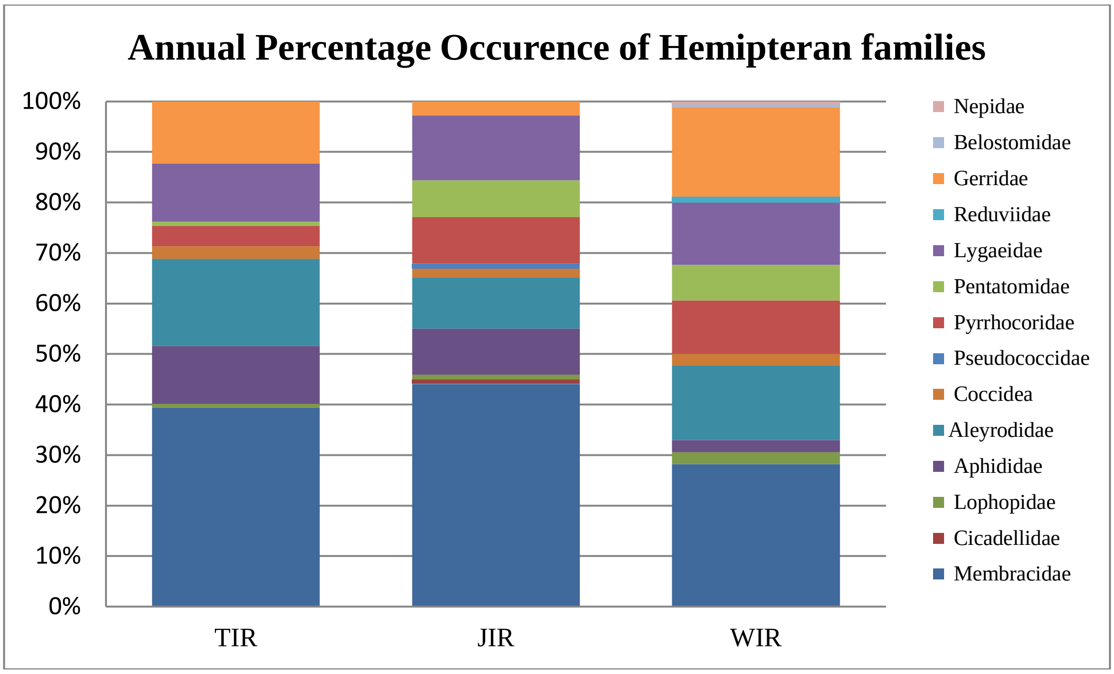


Figure 4.8: Seasonal variation in the Percentage occurrence of fourteen Hemipteran families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

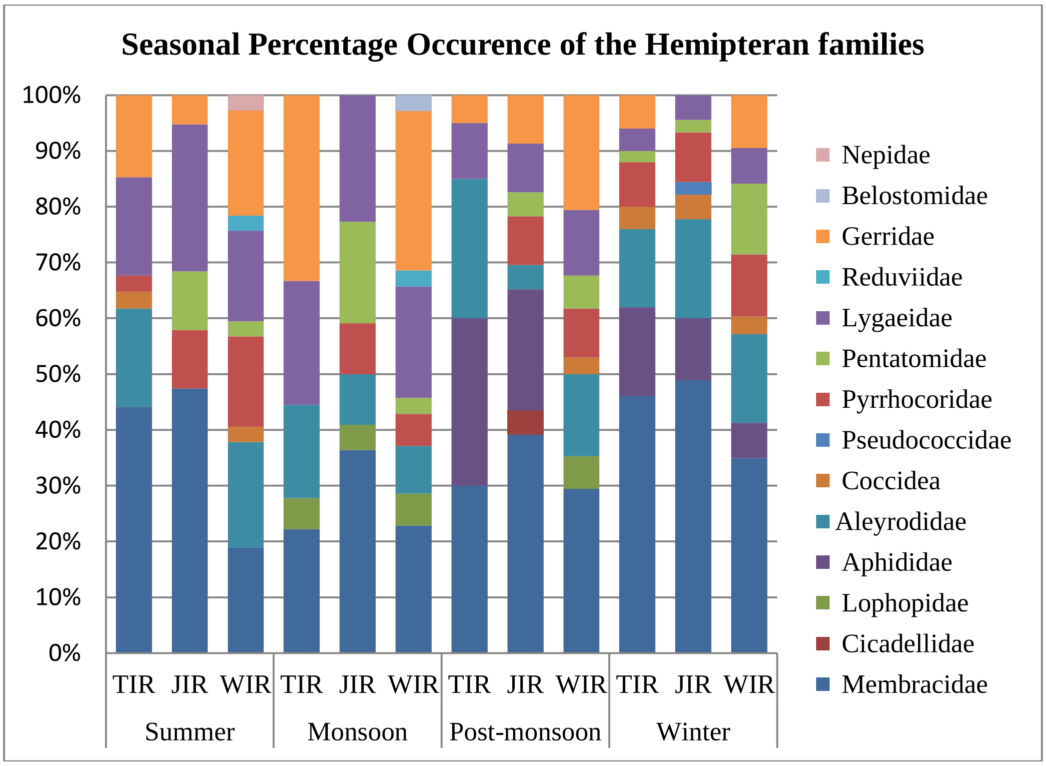


PLATE 9: SOME OF THE HEMIPTERANS OBSERVED IN THE STUDY

Pyrilla perpusilla (Sugarcane leaf-borer)

Gerris remigis (Water strider)

Lygaeus sp. (Milkweed bug)

Oxyrachis tarandus (Treehopper)

Aphis nerii (Aphids)

Bemisia tabacci (White fly)

Discussion

Although in the present study the number of hemipterans around the three reservoirs was comparatively low (Chapter 2) amongst the major order noted, it was represented by 14 families suggesting that the habitats around the reservoirs are good for this group of insects too. Prevalence of nine families at TIR that are common to all three reservoirs indicate that the species belonging to these families are the generalist species adapted to varied climatic conditions. As TIR is under the influence of urban expansion as well as anthropogenic pressures in the form of human exploitation of habitat for washing, bathing and livestock grazing, no specialist species were noted here. Two additional families, Cicadellidae and Pseudococcidae recorded at JIR suggest that though this habitat is modified for agricultural practices over the years it has developed natural vegetation on the earthen dam supporting these families. Pseudococcidae though a family of pest species might be using this vegetation on the earthen dam as alternate host. However, around WIR also three additional families were recorded of which two are of aquatic bugs (Belostomidae and Nepidae) noted only once. It is possible that these two families were present at other two reservoirs too but must have gone unobserved as the study was basically for the terrestrial fauna. Single species of Assasian bug of family Reduviidae was also observed only once at WIR which may a specialist species, observed during its exploratory expedition in the area. Encounter with some accidental species contributes to the species composition (Spungis, 2005). In the present study species like *Oncocephalus sp*. *Belostoma sp.* and *Nepa sp.* were probably the accidental species that contributed to the species composition at WIR.

Most of the hemipteran families observed were terrestrial in habits and only three families were aquatic. Of the three aquatic families, family Gerridae (water striders) was the only family frequently observed because of its habit of walking or moving on the surface of water compared to the other aquatic bugs that are not so frequent on the surface water.

The vegetation composition and structure plays a significant role in the faunal distribution and assemblage (Korkeamaki and Suhonen, 2002; Velasco *et al.,* 1993) as is also noted in the present study. Of the 11 families of terrestrial bugs recorded members of family Membracidae and Lygaeidae were the most frequent. Membracids the honey dew producing Treehoppers represented by three species of genus *Oxyrhachis* reside on the bushes in association with variety of ant species. Their association is mutualistic (Way 1963, Boucher *et al*. 1982; Buckley, 1987; Morales and Beal, 2006) as the honey dew attracts ants (Crocroft, 2003; Sabu *et al*., 2008) and the treehoppers in turn get protection (Wood, 1977; McEvoy, 1979). Both occurred simultaneously in large number indicating that their densities are interdependent. The ant attended membracids are also known to spend much of their lives in colonies (Funkhouser, 1917; Haviland, 1925; Wood 1979; 1984; McEvoy, 1979). The mutualism between the ants and the membracids has also been reported to be favoured by the ecological factors such as predation (McEvoy, 1979; Wood, 1979; Fritz, 1982).

Lygaeidae though represented by a single species *Lygaeus sp.* was one of the most common families. Its presence can be due the presence of its nymphal as well as adult food plants in the area. The nymphal as well as adults of *Lygaeus sp.* were found to be associated with the abundant *Prosopis juliflora* and *Acacia nilotica* present in the surrounding habitats of the reservoirs. A single species observed of family Lophopidae, *Pyrilla perpusilla* (Sugarcane Leaf borer) is a pest of the sugarcane. This species was observed mainly on the bushes present around the reservoirs. However, their presence was rare as sugarcane is not grown in the area.

Aphididae represented by two types of Aphids, *Aphis gossypii* and *Aphis nerii* were more common at TIR as compared to JIR and WIR. Aphids are known pests of various vegetable crops and ornamental plants. The agricultural matrix present around the three reservoirs differs greatly with the crop fields around WIR and JIR compared to the presence of vegetable fields/farm houses around TIR. Another factor influencing the more prevalence of Aphids at TIR can be its proximity to urban habitat where ornamental plants are grown. A third species of Aphid, *Aphis crassivora* common species of the area (Kataria, 2011) may be present around the reservoir but was not observed and needs further investigation on the earthen dam. White flies (*Bemisia tabacci*) belonging to family Aleyroridae were very common hemipterans observed flying as well as on the bushes. Their population explodes in winter when they strike on the face and get inside the mouth while talking. This species has a wide food range and is known to damage various agricultural and ornamental plants (Rabello *et al*., 2008**).** It is a serious pest of Cotton (Vennila, 2011) which is one of the major agricultural crops of Gujarat. Coccidae the scale insects feeding on the plant sap were found irregularly on the bushes in the scrublands indicating that the habitat around the reservoirs is not supporting them. Mealy bugs, family Pseudococcidae observed only at JIR are also the pest of agricultural crops and many ornamental plants in the garden. It is known to infest ornamental plants like *Hibiscus rosasinesis* and almost destroy it (Singh, 2011).

The Red cotton bug (*Dysdercus cingulatus* - Pyrrhocoridae) one of the most common pest of Cotton was observed at all three habitats. It is probably finding the alternate host in the vegetation of scrubland from where it may infest the cotton crops whenever it is grown. The genus *Dysdercus* of this family includes many species inhabiting tropical and subtropical areas all over the world (Freeman 1947; van Doesburg 1968). They are well known as cotton stainers, and are primarily seed feeders (Maxwell-Lefroy 1908; Ahmad and Schaefer 1987). *Dysdercus cingulatus* has wide range of host plants and does not require undergoing diapause as one or the other plant is available throughout the year

(Kohno and Bui Thi, 2005). These were mainly found around WIR and JIR the habitats with more agricultural matrix than TIR.

Pentatomidae, the stink bugs are also the agricultural pests causing various levels of damage to different crops. These are some of the common bugs present in Gujarat. As the habitat surveyed is in the close vicinity of agricultural land their presence around the irrigation reservoir is justified. The hypothesis of Rosenweig (1995) that larger area supports more species may be applied for this family as it is represented by only 1 species *Nezare viridula* at the smallest of the three reservoirs TIR, with one more species *Halyomorpha halys* at JIR and still one more species *Asponogus janus* at the largest reservoir WIR.

Most of the species encountered in the present study were herbivorous sap feeders preferring the soft stem that could be pierced easily. No predatory hemipterans were observed for the terrestrial habitat although predatory water bugs like Belostoma and Nepa were present at WIR only. Predatory bugs generally prefer canopies than the herbivores (Sobek *et al.*, 2009) hence in present study where only herbs and shrubs were present, herbivores were more prevalent.

Abundance rating

As all the hemipterans basically depend on the plants for their survival, the presence or absence of the host plant play a crucial role in their appearance especially in the monsoon dependent terrestrial habitats in semiarid zone of Gujarat. Though the hydro period and hydro spread has increased due to Narmada inundation at WIR and TIR the scrub vegetation in the area starts drying off as monsoon is over and is dry by summer. Hence none of the hemipterans was recorded as abundant according to their encounter rate.

Oxyrhachis tarandus was the most common species in the present study around all the three reservoirs. It is also associated with *Acacia nilotica* and *Prosopis juliflora* which are common in the area especially the later one. Other two species of *Oxyrhachis* were frequently observed at the reservoirs. *Oxyrhachis* is associated with different species of ants that harvest the honey dew (Funkhouser, 1915; Fritz, 1982) and in turn because of the presence of ants treehopper nymphs get protection (Wood, 1977; McEvoy, 1979), probably by decreasing predation (Fritz, 1982, 1983). Although these two groups are not totally dependent on each other for survival and development (Del-Claro and Oliveira, 1999), ant attendance has been shown to significantly increase homopteran survival (Bristow, 1983) and the latter can also do well without ant associates (Hill and Blackmore 1980).

Bemisia tabaci another common species at WIR and TIR and frequent at JIR was more common during the colder part of the year and hence rated common. *Gerris sp.*, a species preferring flowing water was common at WIR, the larger of the three reservoirs with very extensively developed canal system irrigating 8815 hectares of 25 villages, compared to its frequent occurrence at TIR whose canal system irrigates 8 villages and rare at JIR with a single canal and depth achieved only during monsoon and post-monsoon as it is not inundated with Narmada.

Lygaeus sp. another common species of WIR and frequent species at other two reservoirs occurred on the small *Prosopis* bushes. These small bushes were more common around larger reservoir WIR compared to the larger *Prosopis* at JIR and TIR. *Dysdercus cingulatus*, the red cotton bug was frequent at WIR while uncommon around other two reservoirs. As its name suggest it is a pest of cotton and cotton is not cultivated around the three reservoirs and hence it was not observed too frequently. Amongst the three reservoirs both the species of *Aphis* had better abundance rating as “uncommon” around TIR, the reservoir facing pressures of urban expansion than at other two reservoirs where it was rated as rare. As said earlier the vegetable fields present around TIR are more likely to be infested by aphids.

Lastly all the stink bugs and rest of all the hemipterans were observed once or twice hence rated rare. In any habitat the number of species that are either common or abundant is always low because these are the native species adapted to the habitat while the rare species are those that are encountered occasionally during their exploratory movements. Though rare species contribute a significant proportion of species to community structure (Novotny and Basset, 2000; Lucky *et al*., 2002), their importance in determining diversity patterns is unclear (Andrew and Hughes, 2005). In the present study too nearly 50% of the hemipterans species were rare at JIR and WIR which did not contribute significantly to the density but were very important for the species composition or the total species richness of the area.

Jaccard's Similarity index (J)

The three reservoirs being located in the semi arid zone of Gujarat and having a distance of about 25-50Kms face similar type of climatic conditions. This is indicated as most of the hemipteran species were common for the three reservoirs and hence high annual similarity index. The twelve species observed at TIR were present at the other two reservoirs too. These could be the species that adapt to wide variety of plants. The additional species observed at WIR and JIR are possibly the species that are adapted to the different microhabitats available around the reservoirs with higher agricultural matrix As said in earlier chapters, similarity between two habitats depends greatly on the number of species present during that particular period. Hemipterans are more common in winters at all the three reservoirs hence higher similarity during this season mainly influenced by presence of Aphids and white flies. However, lowest similarity in monsoon can be due to highest variability in the species. Further, the time of emergence of many hemipterans from their diapause also varies according to the local climatic conditions leading to lower similarity. Summer being the most unsuitable period only common species were encountered which resulted in moderate similarity. In post-monsoon the difference in the micro-climatic conditions of the three reservoirs resulted in variable similarity between the three reservoirs.

Although the annual similarity index was maximum for TIR and JIR, the seasonal similarity showed large variations due to the appearance and disappearance of the hemipterans during different seasons of the year with the changes at the local level. Nevertheless the low differences between JIR and WIR can be attributed to the presence of same species composition at the two agriculturally dominated habitats in all the seasons of the year.

Species Richness

As discussed in earlier chapters, highest number of species observed at WIR can be attributed to its larger area as is reported by Rosenzweig (1995), while the lowest number at TIR to its comparatively small area.

Species richness is one of the prime determinants in the ecological studies as the number of species in an area determines its health (Magurran, 1988). As far as hemipterans are considered, the low numbers of total species recorded resulted in the low annual species richness. As said earlier, among the three reservoirs the larger one had highest hemipteran species influencing the annual species richness. TIR and JIR are the habitats not only smaller in size but also with same species richness but different species composition compared to that of WIR. At WIR as more surface area with varied microhabitats is available for the different hemipterans along with low level of disturbance by the human as well as grazing cattle, the higher species richness was observed. On the contrary, at TIR the human activities and the grazing pressures are high as compared to other two reservoirs which disturb the bushes, the main niches of most hemipterans in the area.

The hemipterans studied were mainly terrestrial, present on the bushes and sometimes on the ground. During monsoon the ground is wet and bushes are drenched in water creating an unfavourable habitat for these insects. Hence, during monsoon majority of hemipterans disperse and settle at more favourable habitats leading to the low species number as well as density. During post-monsoon, as the rain stops and moisture decreases stabilizing the climatic conditions, the hemipterans start colonizing on the bushes in the vicinity of reservoirs increasing the diversity as well as density. This is achieved maximally in the following season the winter when bush dwelling hemipterans find warmth among foliage. The higher species richness in winter can be assigned to the presence of the white flies and aphids. The plants that encourage the presence of different species along with the Aphids were primarily abundant during this season. Amongst the two reservoirs inundated with Narmada higher species richness at WIR in summer can be attributed to the presence of all the three species of treehoppers along with Milkweed bugs, Red cotton bugs and Water striders while at TIR due to the presence of aphids during early summer. However, at the third reservoir not inundated, the dry inhospitable hot conditions of summer forced the hemipterans to become dormant or shift to other favorable habitats resulting in their low species richness.

Though the trends in species richness were different at the three reservoirs (Table 4.5 Figure 4.6) maximum mean species richness were noted at each during winter indicating that winter is the most favourable season for majority of hemipterans in the semi arid zone of Central Gujarat, India. This is supported by similar trend with different amplitude for density, Shannon Weiner diversity index and Evenness of the hemipterans of the region (Fig. 4.6).

As noted in Chapter 2 the vegetation is removed at Timbi Irrigation reservoir. As many hemipterans like tree-hoppers depend on this vegetation, the removal may have resulted in the overall lower species richness of hemipterans at TIR.

Diversity is an important aspect of species structure in a community. Many attempts have been made to use this character to describe how species and individuals in a community are related (Hairston, 1959). Diversity of animals is more easily expressed in terms of the number of species per number of individuals in a sample collection. The total number of species is not usually related linearly to the total number of individuals but it is related to the chance of finding a new species as sampling increases (Menhinink, 1964). In the present study number of surveys conducted over a period of two years is adequate i.e. altogether 127, during which majority of species are expected to be documented. Hence the difference in species composition at the three reservoirs may be considered as the differences in the habitat availability at the grass root level in the semiarid zone of Gujarat, India.

Density

When annual mean density at the three reservoirs is considered, the non-significant differences indicate that the hemipterans are having more influence at macroclimatic level than at local level. The significant differences in their density were noted only during monsoon whereas during rest of the seasons though there were differences, they were non-significant indicating that these changes were unpredictable with huge fluctuations. Winter being favourable seasons for hemipterans, density was almost equal at all the reservoirs. However, the differences in the density over the seasons suggest that the habitat with similar climatic characteristics may show differences in the density and diversity of the fauna it supports depending not only on the availability of water but also the available flora.

If reservoirs are considered individually, the highest density at **TIR** in summer may be attributed to the good population of the Treehoppers. Ants known to come out of their holes in summer to collect and store food for forthcoming monsoon have been reported to indirectly increase the treehopper density (Morale and Beal, 2006) ultimately increasing the overall hemipteran density in summer. During monsoon as mentioned earlier the rain disturbs the vegetation reducing the presence of hemipterans in the bushes and hence their lowest density. The density in post-monsoon was also low as treehoppers were totally absent during the post-monsoon of 2009. Increase in the density noted during winter is justified as most of the species present were in good numbers and as said earlier during this season the Aphid density also contributed to the hemipteran density.

At **JIR** density during summer, monsoon and post-monsoon did not show much variation as the density contributing species were common in all the three seasons. However, slightly higher density during monsoon may be attributed to the presence of the Milkweed bugs and Red cotton bugs. The highest density reported in winter was again due to the high population of the Aphids and Treehoppers.

An increase in the hemipteran density at WIR from summer through monsoon to post-monsoon to winter indicates that the conditions become favourable at the larger reservoir earlier compared to the smaller reservoirs. Here, absence of tree hoppers in summer and monsoon resulted in the lower density while their appearance in post monsoon with milkweed bugs increased the overall hemipteran density. These established species continued to thrive in winter maintaining the density.

The abundance of plant species like *Prosopis juliflora and Acacia nilotica* around TIR supported higher density of hemipterans in summer (Table 4.5). As JIR did not dried during summer of the study period, the hydro period and hydro spread were comparable with TIR. However, instead of *Acacia* large *Calotropis procera* are present at JIR. As no hemipterans were found on *Calotrpis* the density of hemipterans was comparatively low around JIR during summer. An association between hemipterans and *Acacia*, *Prosopis* and *Calotropis* needs to be evaluated in the area.

Shannon Weiner Diversity index (H') and Evenness (E)

Low values of the **Shannon Weiner index (H')** and **Evenness (E)** recorded suggests the uneven distribution of Hemipterans species around all the three reservoirs. The common hemipteran species in the study were high in numbers while the rare species were represented individually and not in groups decreasing the H' as well as evenness.

Seasonal H'

The diversity indices calculated in the preset study are inter-dependent and hence when the species richness and density were high, the H' and Evenness also increased. The highest mean H' during winter around all the three habitats support the idea that winter is the most favourable season for Hemipterans. However, at TIR, good diversity index was noted in summer too when it was lowest around JIR due to the great differences in number of species present. Less seasonal variations in the H' for three seasons except winter at WIR may be due to the high density of the Treehoppers along with that of Red cotton bug and Milkweed bugs.

Seasonal Evenness (E)

Mono-species dominance of *Oxyrhachis tarandus* resulted in overall low evenness in all the seasons for all the reservoirs. However, as all the ecological parameters are inter-related, the comparatively higher species richness, density and H' led to the comparative higher Evenness in winter. The highest value among all the habitats in all the season was observed for the smaller undisturbed scrubland around JIR where the few species present occurred in comparable numbers.

Percentage Occurrence

Percentage occurrence is the measure to calculate the percentage of a particular species observed in comparison to the other species over a defined duration of time. The annual percentage occurrence of various hemipterans families suggests that members of family Membracidae, the treehoppers were the most widespread species over the span of the study at the three reservoirs. Treehoppers are found more commonly in open and sunny areas (Haviland, 1925; Funkhouser 1915; Ekkens, 1972), the habitats similar to the ones surveyed in present study with ample sunlight. Hence the treehoppers *Oxyrhachis* *tarandus* along with other two species of the same genus contributed considerably in the higher percentage occurrence of this family. These honeydew producing species are found most commonly near plant terminals such as leaf tips, inflorescences, or fruits (Wood, 1984; Del-Claro and Oliveira, 1993*).* Here, the nitrogen concentrations and tending levels by ants; the group having mutual relationship with the treehopper; are much higher (Mateson 1980; Davidson and Epstein, 1989; Bristow, 1991). In the present study too, the treehoppers were abundant and found near the terminal branches of the bushes compared to the main stem. As mentioned earlier majority of families represented by single species influenced the higher percentage occurrence of this family.

The differences in the percentage occurrence of other families may be attributed to the difference in the microclimate and microhabitat at the regional level. This is reflected as second highest percentage occurrence of family Aleyorodidae at TIR, Lygaeidae at JIR and higher percentage occurrence of families Gerridae, Aleyorodidae, Lygaeidaea and Pyrrhocoridae at WIR. These later families brought down the percentage occurrence of family Membracidae at WIR. The results of present study indicate that though at macro climate level each reservoir is located in the semi arid zone of Gujarat India at a distance of 25-50 Kms. from each other, influence of microclimate produces differences in percentage occurrence of various species.

Several families of hemiptera exhibited poor percentage occurrence. These are the families represented by the species which were probably trying to explore new habitats or not able to adapt to the modified habitat due to Narmada inundation and/or human disturbances. These families are Cicadellidae, Lophopidae, Pseudococcidae, Reduviidae, Belostomidae and Nepidae. This needs further investigation. Nevertheless families Gerridae, Aleyrodidae, Lygaeidae and Pyrrocoridae though represented by single species each had good representation contributing significantly to the overall percentage occurrence. From the data collected it could be said that the larger habitats has several microhabitats with different characteristics and hence support higher species diversity compared to the smaller habitats.

Aquatic insects are known to have strong relationship with water surface fluctuations (Ebert and Balko, 1987) hence the declining water level at JIR, the reservoir not inundated with Narmada and totally dependent on monsoon rains, may have been unsuitable for the water striders leading to their absence or less frequent appearance during certain period of the year. Drying of the habitats is another factor that affects the population of the aquatic hemipterans by causing mortality due to unsuitable habitat (Corti *et al* 1997).

Seasonal Differences

Membracidae and Lygaeidae the terrestrial hemipterans prefer *Acacia sp.* and *Prosopis sp.* which are common round the year around the reservoirs and hence these families were represented all throughout the year. As discussed earlier, the variations in the density of the hemipterans may be attributed to the local conditions. Cicadellidae was the family that was absent completely at TIR and WIR while at JIR too it was found only during post-monsoon and hence it could be considered as an accidental encounter. Lophopidae - the Sugarcane leaf-borer was present only during monsoon at all the three reservoirs suggesting that it uses wild grasses as the alternate food resource. Aphididae the family known to occur in post-monsoon and winter in the area (Kataria, 2011) occurred with high percentage occurrence during post-monsoon at TIR. These are the pests of cultivated plants may that be agricultural, vegetable or ornamental plants (McGavin, 1992). Hence, in the absence of their food plants, they might be shifting to the wild grasses growing due to the good rainfall during the study period in the semi arid zone of Central Gujarat.

Aleyrodidae- the White flies are also pests on wide variety of plants and are known to feed on large number of alternative food plants. Their low occurrence at JIR during summer, monsoon and post-monsoon can be basically due to the less availability of food in the vicinity compared to the other two reservoirs where they were present all throughout the year. Their occurrence during winter at JIR may be attributed to their population explosion. However, the presence of this family was rather constant at TIR as compared to its fluctuating occurrence in monsoon at WIR.

Family Coccidae was completely absent during monsoon and post-monsoon which are the wet seasons disturbing the habitat of these insects which prefer sticking to the bark or stem of the tree. Pseudococcidae, *i.e.* the mealy bugs were present only at JIR that too during winter. These are the insect pests of the ornamental plants and were observed only once on the leaves of the *Calotropis*- a milkweed species which was quite unusual.

Pyrrhocoridae was present all throughout the year at JIR and WIR while only in the dry season at TIR. *Dysdercus cingulatus* (Pyrrocoridae) has long been regarded as the most serious cotton pest among the Asian *Dysdercus* species (Maxwell-Lefroy 1908). Though they have a strong preference for host plant species that bear large seeds, like the cotton plants, they have a considerably broad host plant range which serve as their alternative host (Kohno and Bui Thi, 2005). As this is the cotton pest and may shift only to the host plants that bear large seeds like *Hibiscus etc.* which were not common in the area they were observed in very low numbers around the reservoirs. Because of the presence of other hemipteran families during summer and monsoon at WIR the percentage occurrence of Pentatomidae represented though by three species was low compared to JIR which had only 2 species. Being similar to milkweed bugs Reduviid bugs observed only once at WIR during monsoon needs further investigation.

Among the three aquatic families, Gerridae (the water striders) was the only family that was frequent. Das and Gupta (2010) observed that the decreasing water level in Post-monsoon decreases the population of water striders but in the present study the water level was high during post-monsoon when *Gerris sp*. was encountered more frequently compared to its absence during monsoon at JIR. At other two reservoirs it was present all throughout the year. Belostomidae was observed only once during Monsoon and Nepidae during summer at WIR. Both these encounters may be by chance as the aquatic bugs were not searched vigorously as the study was focused on terrestrial insects.

BUTTERFLY DIVERSITY AROUND WETLANDS

Introduction

Order Lepidoptera is one of the most attractive, widespread and widely recognized orders of Class Insecta that include butterflies and moths. This group has played pivotal role in the development of ecological theories (Boggs *et al.*, 2003). They play significant role in the ecosystem as herbivores, pollinators as well as prey (Janzen, 1987a; Barlow and Woiwod, 1989). Being host specific (Janzen, 1988) they also serve as important indicators of the native plant diversity as well as other phytophagous insect taxa (Erhardht and Thomas, 1991). Among the two Lepidopteran groups, 90% species are moths (Janzen, 1988; Young, 1997), while butterflies comprise only 10%. However, due to their dull colouration and crepuscular or nocturnal habits moths are less popular and hence comparatively less documented, while butterflies, being more colourful and diurnal in nature have been extensively observed and have always received more attention.

Being comparatively larger in size, butterflies have always been a subject of interest and probably next to birds in their universal popularity. They are ideal subjects for ecological study in landscapes (Thomas and Malorie, 1985; Pollard and Yates, 1993) and hence one of the most studied insect group. This can be attributed to their great varieties and dramatic transformations during their lifecycle (Gay *et al.,* 1992). This often makes them flagship species (Ali, 2007) among insects due to their high visibility along with relatively known taxonomy (Joshi, 2007; Tiple and Khurad, 2009; Ghazoul, 2002; Ramesh *et al.,* 2010). As they are very sensitive to the changing climatic conditions as well as the habitat (Erhardt, 1985; Kremen, 1992; Scoble, 1992; Simonson *et al.*, 2001; Joshi, 2007; Rajagopal, 2011) they are also considered most appropriate taxonomic group for environmental evaluation (Pollard, 1991). Being pollinators their adults are essential part of any natural ecosystem (Borges *et al.*,2003; Hussain *et al.*,2011) while larvae enact as primary consumers thereby transferring radiant energy trapped by plants to the next trophic level; *i.e.* rendering dual roles as pollinators and as energy transferers (Sreekumar and Balakrishnan, 2001).

Butterflies are also important components of food chain as they are prey species for large number of organisms like birds, reptiles as well as certain insects and hence occupy a vital position in ecosystems. Their occurrence and diversity are considered as good indicators of the health of any given terrestrial biotope (Kunte, 2000; Aluri and Rao, 2002; Thomas, 2005). As herbivorous insects, distribution of their larvae and nectar host plants has a distinct impact on their status (Culin, 1997; Raju, 2004). The ability of these herbivorous insects to feed on plants has been demonstrated to be intricately linked to the plant taxonomic diversity (Mitter *et al.*, 1988) that involves competition between plants and insects (Dawkins and Krebs, 1979).

Butterflies are the most tantalizing and beautiful species attracting large numbers of researchers and hence ample literature is available for the butterfly fauna. Several studies have been conducted on forest butterflies (Pandharipande, 1990; Murray, 2000; Fermon *et al.*,2001; Arun, 2008; Jalil *et al.*,2008; Sundufu and Dumbuya, 2008; Wadatkar and Kasambe, 2008; Peixoto and Benson, 2009; Sharmila, 2009) as well as of the urban butterfly fauna (Ruszczyk, 1986; Kunte, 2001; Raut and Pendharkar, 2010, Tiple and Khurad, 2009; Hussain *et al.*, 2011; Rajagopal *et al.*, 2011; Tiple *et al.*, 2011). Several studies are also conducted on butterflies in Grasslands (Balmer and Erhardt, 2000; Pryke and Samways, 2001; Collinge, 2003; Schneider, 2003; Stefanescu *et al.*, 2009) and mountains (Gutiérrez and Menéndez, 1995; Patil, 2011) but the studies of the butterfly fauna around wetlands are almost nil.

The Indian region has a very rich butterfly fauna of about 1501 species belonging to nearly 320 genera (Gaonkar, 1996) amounting to nearly one fifth of the world butterfly species (Kunte, 2000). Of these, peninsular India hosts 350 species, with 331 of Western Ghats and 313 from South India (Gaonkar, 1996). In Gujarat also, 193 species of butterfly have been reported by several authors (see Parasharya and Jani, 2007). Of these 74 species are Western Ghats species reported from Northern range of Western Ghats that extends up to South Gujarat. Because of this South Gujarat tops in butterfly diversity with 192 observed species, followed by Central Gujarat with 87, Saurasthra with 78, Kachchh with 47 and North Gujarat with 26 (Parasharya and Jani, 2007).

Central Gujarat falls in the semi-arid zone where the rainfall is low and hence the diversity and density of butterflies is also low compared to South Gujarat that receives higher rainfall. The butterfly fauna of some habitats of Central Gujarat have been documented. These studies include 59 species from Kheda district (Aldrich, 1946), 47 from Anand district (Rohit, 2001) and 44 from Ratanmahal Wildlife Sanctuary (Bhalodia *et al.*, 2002). A study in the Jambughoda Wildlife Sanctuary- nearest to the present study area reported 33 butterfly species (Anon, 2006). Additionally, the study conducted by Kumar and Shiva Kumar (2007) in Vadodara reports 42 butterfly species belonging to 31 genera and 5 families.

Nearly all the insect groups show seasonality and butterflies are no exception to it. Seasonal fluctuations in butterfly diversity and density are influenced by environmental factors including temperature, photoperiod, rainfall, humidity, variation in the availability of food resources, and vegetation cover such as herbs and shrubs (Anu, 2006; Anu *et al.*, 2009; Shanthi *et al.*, 2009; Tiple and Khurad, 2009). As rainfall and plant phenology, two interrelated factors influence the life histories of phytophagous butterflies these form a model group for ecological studies specifically pertaining to seasonality (Wolda, 1978; 1988; Barua, 2010). It is now known that the population dynamics of many species of butterflies are strictly governed by seasonal environmental patterns and constrained by climate (Pollard, 1979; 1988; Kunte, 1997; Barua 2010).

Composition of butterflies has also been correlated with economic activities (Monastyrskii, 2007).

With this background, in the present study an attempt is made to document the butterfly fauna, present around the three irrigation reservoirs in the semi arid zone of Central Gujarat which are facing different level of human disturbances and are surrounded by different land- matrix, along with the seasonal dynamics in their density and diversity.

Results

Classification of butterflies is based on Kehimkar (2008). Of the two super-families of butterflies, Hesperiodea and Papilionoidea, only the later has been recorded in the study area represented by all four families - Papilionidae, Pieridae, Lycaenidae and Nymphalidae.

Number of species (Table 5.1, Fig. 5.1)

Total 49 species of butterflies belonging to 4 families and a single super-family were observed around the three reservoirs. All the four families were present at all three reservoirs. Highest 42 species of butterflies were recorded around WIR which include 4 species belonging to family Papilionidae - swallowtail butterflies, 13 to Pieridae- Whites and yellows, 9 to Lycaenidae- the blues and 16 to Nymphalidae- brush footed butterflies. At TIR, 34 species were recorded with 4 species of Papilionids, 13 Pierids, 6 Lycaenids and 11 Nymphalids while around JIR 36 species were recorded that includes 2 Papilionids, 16 Pierids, 7 Lycaenids and 11 Nymphalids.

Abundance rating (Table 5.2, Fig.5.2, Table 5.7)

Out of total 49 species observed over the study period, 2 species each were abundant at TIR and WIR while a single species at JIR. Plain tiger *Danaus chrysippus* was abundant around all the three reservoirs, while Tiny grass blue *Zizina hylax* was abundant at TIR and Lesser grass blue *Zizina otis* at WIR. The common species numbered 1, 2 and 6 at TIR, JIR and WIR respectively. These include Common grass yellow *(Eurema hecabe*) at all the three habitats, Lesser grass blue (*Z. otis*) around JIR and Gram blue (*Euchrysops cjenus*), Tiny Grass blue (*Z. hylax*), Blue pansy (*Junonia orithya*), Peacock pansy (*Junonia almana*) and Danaid eggfly (*Hypolimnus missippus*) around WIR. Five species were frequent at TIR, while 7 at JIR and 6 at WIR. These were Common Jezbel (*Delias eucharis*) around TIR and WIR, while Gram blue (*E. cjenus*) and Peacock pansy (*J. almana*) at TIR and JIR, while Lesser Grass blue (*Z. otis*) and Blue pansy (*J. orithya*) at TIR. The other frequent species at JIR include White orange tip (*Ixias marianne*), Stripped Pierrot (*Taracus indicus*), Tiny grass blue (*Z. hylax*), Lemon pansy (*Junonia lemonias*) and Danaid eggfly (*H. missippus*) and that at WIR Common emigrant (*Catopsilia pomona*), Mottled Emigrant (*Catopsilia pyranthe*), Indian cupid (*Everes lacturnus*), Stripped Tiger (*Danuas genutia*) and Tawny coster (*Acraea terpsicore*). Uncommon species were more in number accounting to 8 at TIR, 10 at JIR and 7 at WIR. All those species that were absent at one or more of the three reservoirs were rare. Maximum 21 species were rare around WIR while TIR and JIR had 18 and 16 rare species respectively.

Jaccard's Similarity Index (J) (Table 5.3)

The **annual** Jaccard's similarity index was highest 0.75 between TIR and JIR, while between TIR and WIR, and JIR and WIR it was 0.65 and 0.66 respectively (**Fig. 5.3**). The **seasonal** jaccard's similarity index was highest during monsoon with 0.7 for WIR and TIR, while 0.61 for JIR and WIR, and 0.64 for TIR and JIR. Jaccard's similarity index was lowest during winter for all the three reservoirs with 49% species common between WIR and JIR, 40 % between TIR and WIR and 33% between TIR and JIR. In Post monsoon the similarity index ranged from 0.55 to 0.6 while in summer from 0.44 to 0.54 (**Fig. 5.4**).

Annual Differences in the Mean Species Richness, Density, Shannon Weiner Diversity index (H') and Evenness (E) (Table 5.4, Figure 5.5)

Species Richness – The annual mean species richness of butterflies was maximum 9.33 ± 0.68 species at WIR and minimum 5.69 ± 0.52 species at TIR, while at JIR it was 7.9 ± 0.62 species. The differences in the species richness were highly significant ($p < 0.001$, $F_{(2, 125)}$ 9.48) between the three reservoirs.

Density – The annual mean density was maximum 0.011± 0.003 individuals/10m^2/min at TIR and minimum 0.005 ± 0.0009 individuals/10m^2/min at WIR while at JIR annual density was 0.008 ± 0.0011 individuals/10m^2/min and varied non significantly ($p > 0.05$, $F_{(2, 125)}$ 1.8) between the three reservoirs.

Shannon Weiner species diversity index (H') and Evenness (E) – The mean H' and mean Evenness were highest 1.7 ± 0.09 and 0.82 ± 0.017 respectively for butterflies at WIR and lowest 1.14 ± 0.08 and 0.7 ± 0.04 at TIR. For JIR, they were 1.61 ± 0.09 and 0.79 ± 0.04 respectively. The diversity index varied highly significantly ($p < 0.001$, $F_{(2, 125)}$ 12.26) while the Evenness varied significantly ($p < 0.05$, $F_{(2, 125)}$ 3.69) among the three reservoirs.

Seasonal Differences in the Mean Species Richness, Density, Shannon Weiner Diversity index (H') and Evenness (E) (Table 5.5, Figure 5.6)

Species Richness

Seasonal variations around Each Reservoir

TIR– In post monsoon the mean species richness was highest 8.73 ± 0.92 species which decreased to lowest 3.58 ± 0.56 species in winter and was maintained at 3.92 ± 0.57 species in summer and showed an increase in monsoon with 7 ± 1.3 species. The seasonal variations were highly significant ($p < 0.001$, $F_{(3,41)}$ 8.73).

JIR – Mean Species richness for JIR was highest 10.13 ± 1.56 species and 10.14 ± 0.83 species during monsoon and post monsoon respectively and lowest 5.7 ± 1.01 species in winter. In summer it was 7.17 ± 1.08 species. Seasonal variations were significant ($p < 0.05$, $F_{(3,34)}$ 3.54).

WIR – Mean Species richness was maximum 13.7 ± 1.03 species in post monsoon, which decreased to 10.25 ± 0.88 species in winter and reached minimum 6.08 ± 1.14 species in summer. In monsoon it was 7.91 ± 1.37 species. The seasonal variations were highly significant ($p < 0.001$, $F_{(3,41)}$ 8.33).

Differences among the reservoirs

Among the three habitats, the highest mean species richness during summer and monsoon were observed at JIR while lowest at TIR. Moderate species richness was recorded at WIR in both the seasons. The differences among three reservoirs were non-significant **(**$p > 0.05$) for both the seasons with $F_{(2,33)}$ 2.95 in summer and $F_{(2,26)}$1.19 in monsoon. In post monsoon as well as winter the mean species richness was maximum at WIR and minimum at TIR while moderate at JIR with moderately significant differences ($p < 0.01$, $F_{(2, 25)}$ 7.74) noted in post-monsoon and highly significant differences ($p < 0.001$, $F_{(2, 32)}$ 18.63) in winter .

Density

Variations were observed in the density at all the three reservoirs with the minimum and maximum density observed in different seasons of the year at different reservoirs.

Seasonal variations around Each Reservoir

TIR – The mean density was maximum 0.03 ± 0.01 individuals/10m^2/min in post monsoon and minimum 0.002± 0.0007 individuals/10m^2/min in summer. During monsoon and winter it was 0.007 ± 0.002 individuals/10m^2/min and 0.005 ± 0.002 individuals/10m^2/min respectively. Moderately significant ($p < 0.01$, $F_{(3,41)}$ 5.82) seasonal variations were observed at TIR.

JIR - The mean density of butterflies was maximum 0.016 ± 0.003 individuals/10m^2/min in post monsoon while 0.005 ± 0.001 individuals/10m^2/min in winter, 0.005 ± 0.002

individuals/10m^2/min in summer and 0.01 ± 0.003 individuals/10m^2/min in monsoon. The seasonal variations were moderately significant ($p < 0.01$, $F_{(3,34)}$ 5.75).

WIR- Mean density of butterflies at WIR was highest 0.01 ± 0.002 individuals/10m^2/min in winter and lowest 0.002 ± 0.0006 individuals/10m^2/min in summer and varied highly significantly ($p < 0.001$, $F_{(3,41)}$ 6.57) across the seasons. In monsoon and post monsoon the density was 0.004 ± 0.001 individuals/10m^2/min and 0.005 ± 0.0008 individuals/10m^2/min respectively.

Differences among the reservoirs

When the differences among the three reservoirs are considered for mean density it was observed that during summer and monsoon the mean density was maximum at JIR while lower at both other reservoirs. The seasonal differences among the three reservoirs were non-significant ($p > 0.05$) in both the seasons with $F_{(2, 33)}$ 2.26 and $F_{(2,26)}$ 2.07 in summer and monsoon respectively. The highest density in post-monsoon was recorded around TIR followed by JIR and lowest around WIR. The differences among the reservoirs were non-significant with $F_{(2,25)}$ 3.31. In winter, the highest mean density was recorded at WIR while it was low at TIR and JIR and differed significantly ($p < 0.05$, $F_{(2, 32)}$ 3.55).

Shannon Weiner Species Diversity Index (H')

Seasonal variations around Each Reservoir

TIR– Mean H' was maximum 1.37 ± 0.18 in monsoon at TIR followed by 1.25 ± 0.15 in Post monsoon and minimum 0.9 ± 0.18 in winter. During summer it was 1.08 ± 0.15 and showed non- significant ($p > 0.05$, $F_{(3,41)}$ 1.53) seasonal variations.

JIR – Mean H' varied non significantly ($p > 0.05$, $F_{(3,34)}$ 1.49) at JIR with nearly same higher values during wet seasons, monsoon and post monsoon (1.85 ± 0.15 and 1.8 ± 0.05 respectively) while lower values in dry seasons, summer as well as winter (1.46 ± 0.21 and 1.42 ± 0.2 respectively).

WIR - Mean H' for WIR was maximum 2.02 ± 0.08 in post monsoon and was maintained at 1.98 ± 0.1 in winter while decreased to minimum 1.27 ± 0.19 in summer and again increased to 1.54 ± 0.19 in monsoon. The variations were significant at $p < 0.01$ ($F_{(3,41)}$ 5.93) across the seasons.

Differences among the reservoirs

Mean H' in summer and monsoon were maximum at JIR while minimum at TIR with non-significant differences at $F_{(2,33)}$ 1.07 and $F_{(2,26)}$ 1.73 respectively. In post monsoon and winter it was highest at WIR and lowest at TIR with highly significant differences ($p < 0.001$) with $F_{(2,25)}$ 13.23 and $F_{(2, 32)}$ 12.17 respectively.

Evenness (E)

Seasonal variations around Each Reservoir

TIR– Mean evenness was maximum 0.78 ± 0.08 in summer and minimum 0.58 ± 0.06 in post monsoon, while it was 0.75 ± 0.05 and 0.67 ± 0.11 in monsoon and winter respectively with $p > 0.05$ across the seasons ($F_{(3,41)}$ 1.4).

JIR- Mean evenness varied non significantly ($p > 0.05$, $F_{(3,34)}$ 0.71) with 0.82 ± 0.03 in monsoon, 0.81 ± 0.02 in post monsoon, 0.83 ± 0.1 in winter and 0.7 ± 0.1 in summer.

WIR- Mean evenness was nearly same in all the seasons with 0.8 ± 0.05 in summer, 0.8 ± 0.03 in monsoon, 0.79 ± 0.02 in post monsoon and 0.86 ± 0.02 in winter and hence varied non significantly ($p > 0.05$, $F_{(3,41)}$ 0.93).

Differences among the reservoirs

There were no major differences in the evenness between the three reservoirs in summer and monsoon when the evenness ranged between 0.7 to 0.8 and varied non- significantly with $F_{(2, 33)}$ 0.52 and $F_{(2,26)}$ 0.79. The difference was noted to be highly significant ($p < 0.001$, $F_{(2,25)}$ 9.34) in post monsoon with higher values at JIR and WIR. In winter higher evenness was noted for JIR and WIR which differed non-significantly between three reserviors with $F_{(2, 32)}$ 1.84.

Annual Percentage Occurrence (Table 5.6, Figure 5.7)

The annual percentage occurrence suggests that Nymphalidae was the most dominant family with 37%, 33.77% and 42 % of the total butterfly population at TIR, JIR and WIR respectively, while Papilionidae was the rarest family with 6.64%, 3.98% and 5.23 % of occurrence. At TIR, Nymphalidae was followed by Pieridae and Lycaenidae with 29.3% and 27% of the total butterfly occurrence while at JIR Pieridae also had same 33.77 % occurrence as that of Nymphalidae followed by 28.48% of Lycaenidae. At WIR, Lycaenidae was the second dominant family with 28.98% followed by 23.75% of Pieridae.

Seasonal Percentage Occurrence (Table 5.6, Figure 5.8)

The dominant family varied with respect to the seasons. However, family Nymphalidae, which dominated annually, was dominant during summer and post-monsoon at the three reservoirs and during winter at WIR. While Lycaenidae dominated at WIR during monsoon and at TIR and JIR during winter. Pieridae was found to dominate at TIR and JIR during monsoon. As observed for the annual percentage occurrence, the seasonal percentage occurrence also clearly shows the rarity of family Papilionidae. However, during post-monsoon, it occurred more frequently at JIR as compared to other seasons of the year.

Seasonal differences around reservoirs

As said for earlier chapters, for Lepidoptera also percentage occurrence of different families in a particular season at each reservoir is taken into consideration.

Summer

TIR- Nymphalidae was the most dominant family at TIR during summer with 48.94% of the butterfly population. Papilionidae was the rarest with 8.5% while Pieridae and Lycaenidae each had same 21.27 % occurrence.

JIR – At JIR, Pieridae and Nymphalidae each constituted 36% of butterflies, while Lycaenidae constituted 24.42% and Papilionidae least 3.49% of the total butterfly population.

WIR – At WIR great differences were observed in the percentage occurrence during summer with minimum 8.22% Papilionidae, 17.8% Pieridae, 24.65% Lycaenidae and maximum 49% Nymphalidae.

Monsoon

TIR – In monsoon the highest percentage of butterflies was contributed by Pieridae with 45.7% while Lycaenidae and Nymphalidae constituted almost same 24.43% and 24.29% of the total butterflies and Papilionidae lowest 8.57%.

JIR – At JIR again the highest percentage was contributed by Pieridae with 38.27% followed by 30.86% Nymphalidae, 28.4% Lycaenidae and lowest 2.47% of Papilionidae.

WIR – At WIR, Lycaenidae had the highest 36.37% occurrence closely followed by 34% of Nymphalidae, 25% of Pieridae and only 4.55% of Papilionidae.

Post-Monsoon

TIR – Nymphalidae was the most dominant family with 39.58% occurrence. Pieridae followed with 29% and Lycaenidae with 25% of the total butterflies. Papilionidae contributed only 6.25% of the total butterflies.

JIR – Nymphalidae dominated with 40.84% of the butterfly population, while Pieridae and Lycaenidae contributed 25.35% each and Papilionidae lowest 8.45% .

WIR – Again Nymphalidae was the most dominant family with 44.53% of the total butterfly population. It was followed by Pieridae with 27%, Lycaenidae with 21.17% and Papilionidae with 7.3% of total post-monsoon butterfly population.

Winter

TIR - Lycaenidae was the most dominant family with 46.5% of the butterfly population closely followed by Nymphalidae with 39.53%. During this season Pieridae showed low percentage occurrence of 11.62% along with lowest 2.32% of Papilionidae.

JIR – Lycaenidae dominated at JIR in winter with 37.5% closely followed by Pieridae with 34.38%. Nymphalidae was represented by 26.56% while Papilionidae with only 1.56%.

WIR – Nymphalidae was the most dominate family with 40.65%, followed by 34.96% of Lycaenidae, 22.77% Pieridae and lowest 1.68% Papilionidae.

Differences among the habitats

In **summer** the percentage occurrence of Pieridae was maximum at JIR as compared to other two reservoirs while that of Papilionidae was low among the three reservoirs. Lycaenidae had more or less same percentage of occurrence at all the three reservoirs while Nymphalidae had lower percentage occurrence at JIR. In **monsoon** Papilionidae and Pieridae had higher percentage occurrence at TIR as compared to other two reservoirs while Lycaenidae and Nymphalidae were more dominant at WIR. During **post-monsoon** Papilionidae was more frequent at JIR than other two reservoirs, Pieridae had maximum occurrence at TIR and Lycaenidae did not show significant difference among the three reservoirs while Nymphalidae had highest percentage occurrence at WIR. During **winter** Pieridae had highest percentage occurrence at JIR among the three reservoirs while Papilionidae had very low percentage occurrence at all three reservoirs. Lycaenidae had highest percentage occurrence at TIR while Nymphalidae had almost same percentage occurrence at TIR and WIR.

When the seasonal differences in the percentage occurrence of the families at the single site for a single season are considered in the decreasing order it is as follows.

TIR – Summer –Nymphalidae > Pieridae = Lycaenidae > Papilionidae

Monsoon - Pieridae > Lycaenidae > Nymphalidae > Papilionidae

Post monsoon - Nymphalidae > Pieridae > Lycaenidae > Papilionidae

Winter - Lycaenidae > Nymphalidae > Pieridae > Papilionidae

JIR - Summer - Nymphalidae = Pieridae > Lycaenidae > Papilionidae

Monsoon - Pieridae > Nymphalidae > Lycaenidae > Papilionidae

Post monsoon - Nymphalidae > Lycaenidae = Pieridae > Papilionidae

Winter - Lycaenidae > Pieridae > Nymphalidae > Papilionidae

WIR - Summer - Nymphalidae > Lycaenidae > Pieridae > Papilionidae

Monsoon - Lycaenidae > Nymphalidae > Pieridae > Papilionidae

Post monsoon - Nymphalidae > Pieridae > Lycaenidae > Papilionidae

Winter - Nymphalidae > Lycaenidae > Pieridae > Papilionidae

Table 5.1: Number of species belonging to different Butterfly families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Papilionidae (5)	**Pieridae (16)**	**Lycaenidae (10)**	**Nymphalidae (18)**	**TOTAL**
TIR	4	13	6	11	34
JIR	2	16	7	11	36
WIR	4	13	9	16	42

Table 5.2: Abundance rating of Butterfly species encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Abundant	**Common**	**Frequent**	**Uncommon**	**Rare**
TIR	2	1	5	8	18
JIR	1	2	7	10	16
WIR	2	6	6	7	21

Table 5.3: Annual and Seasonal Jaccard's Similaity Index (J) between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Annual		**Summer**		**Monsoon**		**Post monsoon**		**Winter**	
	TIR	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**
WIR	0.65	0.66	0.45	0.54	0.7	0.61	0.55	0.56	0.4	0.49
JIR	0.75	-	0.44	-	0.64	-	0.6	-	0.33	-

Table 5.4: Annual mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of the butterflies at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Species Richness (***) $F_{(2,125)}$ 9.48	**Density (ns) $F_{(2,125)}$ 1.8**	**Shannon Weiner index (***) $F_{(2,125)}$ 12.26**	**Evenness (*) $F_{(2,125)}$ 3.69**
TIR	5.69 ± 0.52	0.011 ± 0.003	1.14 ± 0.08	0.7 ± 0.04
JIR	7.9 ± 0.62	0.008 ± 0.0011	1.61 ± 0.09	0.79 ± 0.04
WIR	9.33 ± 0.68	0.0057 ± 0.0009	1.7 ± 0.09	0.82 ± 0.017

Table 5.5: Seasonal variations in the mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of the butterflies at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

			Summer	**Monsoon**	**Post monsoon**	**Winter**
Species Richness		**Among Reservoirs / Within Reservoirs**	**(ns) $F_{(2,33)}$ 2.95**	**(ns) $F_{(2,26)}$**1.19	**(**) $F_{(2,25)}$ 7.74**	**(***) $F_{(2,32)}$ 18.63**
	TIR	**(***) $F_{(3,41)}$ 8.73**	3.92 ± 0.57	7 ± 1.3	8.73 ± 0.92	3.58 ± 0.56
	JIR	**(*) $F_{(3,34)}$ 3.54**	7.17 ± 1.08	10.13 ± 1.56	10.14 ± 0.83	5.7 ± 1.01
	WIR	**(***) $F_{(3,41)}$ 8.33**	6.08 ± 1.14	7.91 ± 1.37	13.7 ± 1.03	10.25 ± 0.88
Density			**(ns) $F_{(2,33)}$ 2.26**	**(ns) $F_{(2,26)}$ 2.07**	**(ns) $F_{(2,25)}$ 3.31**	**(*)$F_{(2,32)}$ 3.55**
	TIR	**(**) $F_{(3,41)}$ 5.82**	0.002 ± 0.0007	0.007 ± 0.002	0.031 ± 0.01	0.005 ± 0.002
	JIR	**(**) $F_{(3,34)}$ 5.75**	0.005 ± 0.002	0.01 ± 0.003	0.016 ± 0.003	0.005 ± 0.001
	WIR	**(***) $F_{(3,41)}$ 6.57**	0.002± 0.0006	0.004 ± 0.0011	0.005 ± 0.0008	0.011 ± 0.002
Shannon Weiner index (H')			**(ns) $F_{(2,33)}$ 1.07**	**(ns) $F_{(2,26)}$ 1.73**	**(***)$F_{(2,25)}$ 13.23**	**(***)$F_{(2,32)}$ 12.17**
	TIR	**(ns) $F_{(3,41)}$ 1.53**	1.08 ± 0.15	1.37 ± 0.18	1.25 ± 0.15	0.9 ± 0.18
	JIR	**(ns) $F_{(3,34)}$ 1.49**	1.46 ± 0.21	1.85 ± 0.15	1.8 ± 0.05	1.42 ± 0.2
	WIR	**(**) $F_{(3,41)}$ 5.93**	1.27 ± 0.19	1.54 ± 0.19	2.02 ± 0.08	1.98 ± 0.1
Evenness (E)			**(ns) $F_{(2,33)}$ 0.52**	**(ns) $F_{(2,26)}$ 0.79**	**(***)$F_{(2,25)}$ 9.34**	**(ns) $F_{(2,32)}$ 1.84**
	TIR	**(ns) $F_{(3,41)}$ 1.4**	0.78 ±0.08	0.75 ± 0.05	0.58 ± 0.06	0.67 ±0.11
	JIR	**(ns) $F_{(3,34)}$ 0.71**	0.7 ± 0.1	0.82 ± 0.03	0.81 ± 0.02	0.83 ± 0.1
	WIR	**(ns) $F_{(3,41)}$0.93**	0.8 ± 0.05	0.8 ± 0.03	0.79 ± 0.02	0.86 ± 0.02

Table 5.6: Annual and Seasonal Percentage Occurrence of the butterfly families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

Seasons		**Habitats**	**Papilionidae**	**Pieridae**	**Lycaenidae**	**Nymphalidae**
ANNUAL		TIR	6.64 %	29.3 %	27 %	37.1 %
		JIR	3.98 %	33.77 %	28.48 %	33.77 %
		WIR	5.23 %	23.75 %	28.98 %	42%
SEASONAL	**SUMMER**	TIR	8.5 %	21.27 %	21.27 %	48.94 %
		JIR	3.49 %	36 %	24.42 %	36 %
		WIR	8.22 %	17.8 %	24.65 %	49.31 %
	MONSOON	TIR	8.57 %	45.7 %	24.43 %	24.29 %
		JIR	2.47 %	38.27 %	28.4 %	30.86 %
		WIR	4.55 %	25 %	36.37 %	34.1 %
	POST MONSOON	TIR	6.25 %	29.2 %	25 %	39.58 %
		JIR	8.45 %	25.35 %	25.35 %	40.84 %
		WIR	7.3 %	27 %	21.17 %	44.53 %
	WINTER	TIR	2.32 %	11.62 %	46.5 %	39. 53 %
		JIR	1.56 %	34.38 %	37.5 %	26.56 %
		WIR	1.68 %	22.77 %	34.96 %	40.65 %

Table 5.7 - Abundance rating of the Butterflies observed around three reservoirs

Sr. No	Common Name	Scientific Name	TIR	JIR	WIR
	Family: Papilionidae				
1	Common Rose	*Atrophaneura aristolochiae*	U		U
2	Crimson Rose	*Atrophaneura hector*	R		
3	Lime Butterfly	*Papilio demoleus*	U	U	U
4	Common Mormon	*Papilio polytes*			R
5	Tailed Jay	*Graphium agammnon*	R	R	R
	Family: Pieridae				
6	Plain Sulphur	*Dercas lycorias*	R	R	R
7	Psyche	*Leptosia nina*	R	U	R
8	Common Jezbel	*Delias eucharis*	F	U	F
9	Indian Cabbage White	*Pieris canidia*	R	R	
10	Common Gull	*Cepora nerissa*	R	R	R
11	Pioneer	*Belenois aurota*	R	R	R
12	White Orange tip	*Ixias marianne*	U	F	U
13	Yellow Orange tip	*Ixias pyrene*	R	R	R
14	Great Orange tip	*Hebomoia glaucippe*		R	
15	Common Emigrant	*Catopsilia pomona*	U	U	F
16	Mottled Emigrant	*Catopsilia pyranthe*	U	U	F
17	Common Grass Yellow	*Eurema hecaba*	C	C	C
18	Spotless Grass yellow	*Eurema laeta*		R	R
19	Common Wanderer	*Pareronia valeria*	R	U	R
20	Crimson tip	*Calotis danae*		R	
21	Small Salmon Arab	*Colotis amata*	U	U	R
	Family: Lycaenidae				
22	Forget-me-not	*Catochrysops strabo*			R
23	Stripped Pierriot	*Tarucus indica*	R	F	U
24	Common pierriot	*Castalius rosimon*		R	R
25	Rounded Pierriot	*Tarucus nara*		R	
26	Indian cupid	*Everes lacturnus*	R	U	F
27	Gram blue	*Euchrysops cnejus*	F	F	C
28	Lesser Grass blue	*Zizina otis*	F	C	A
29	Tiny Grass blue	*Zizina hylax*	A	F	C
30	Grass jewel	*Freyeria trochylus*			R
31	Pea blue	*Lampides boeticus*	R		R
	Family: Nymphalidae				
32	Plain Tiger	*Danaus chrysippus*	A	A	A
33	Stripped Tiger	*Danaus genutia*	R	U	F
34	Common Crow	*Euploea core*	U	R	U
35	Blue Tiger	*Tirumala limniace*			R
36	Common Evening Brown	*Melanitis leda*			R
37	Common Castor	*Ariadne merione*	R	R	
38	Joker	*Byblia ilithyia*			R
39	Yellow Pansy	*Junonia hierta*	R		
40	Blue pansy	*Junonia orithya*	F	U	C
41	Peacock pancy	*Junonia almana*	F	F	C
42	Lemon pansy	*Junonia lemonias*		F	R
43	Grey Pansy	*Junonia atlites*	R	R	U
44	Chocolate pansy	*Junonia iphita*			R
45	Painted Lady	*Vanessa cardui*	R	R	R
46	Danaid eggfly	*Hypolimnas missipus*	U	F	C
47	Great eggfly	*Hypolimnas bolina*			R
48	Baronet	*Euthalia nais*			U
49	Tawny coster	*Acraea terpsicore*	R	R	F

Figure 5.1: Number of butterfly species belonging to different families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

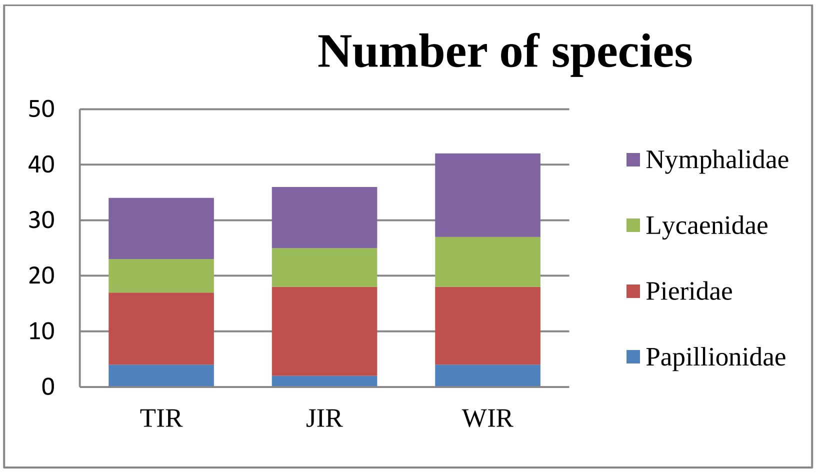


Figure 5.2: Abundance rating of the Butterfly species encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

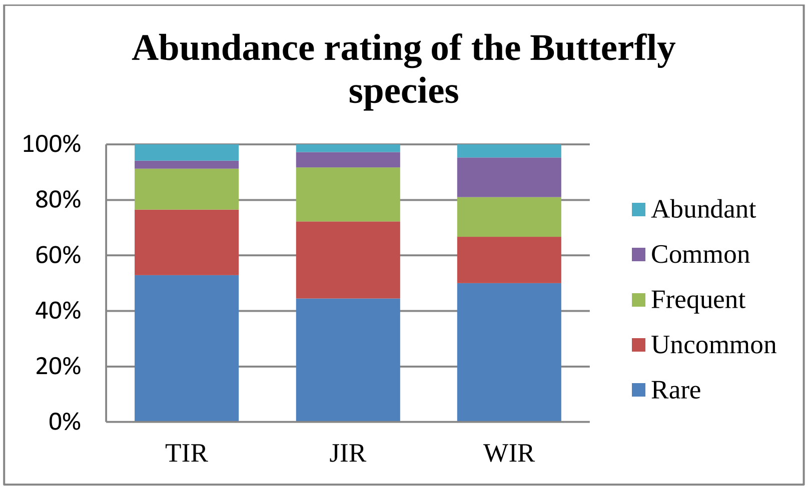


Figure 5.3: Annual Jaccard's similarity Index for the butterflies between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

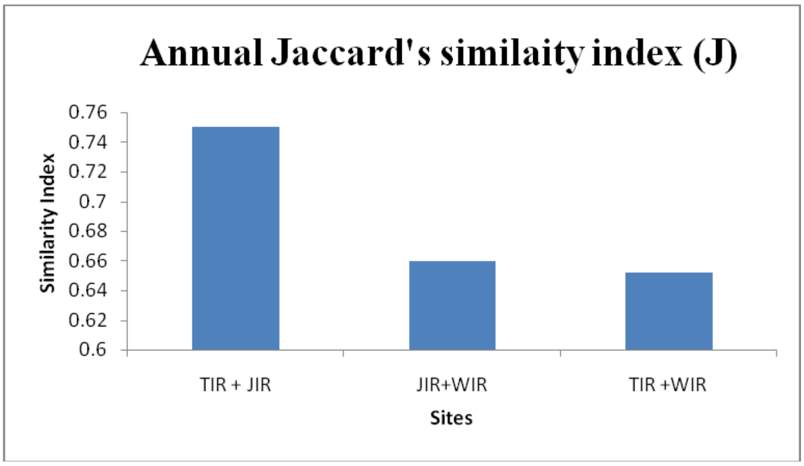


Figure 5.4: Seasonal Jaccard's similarity Index for the butterflies between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

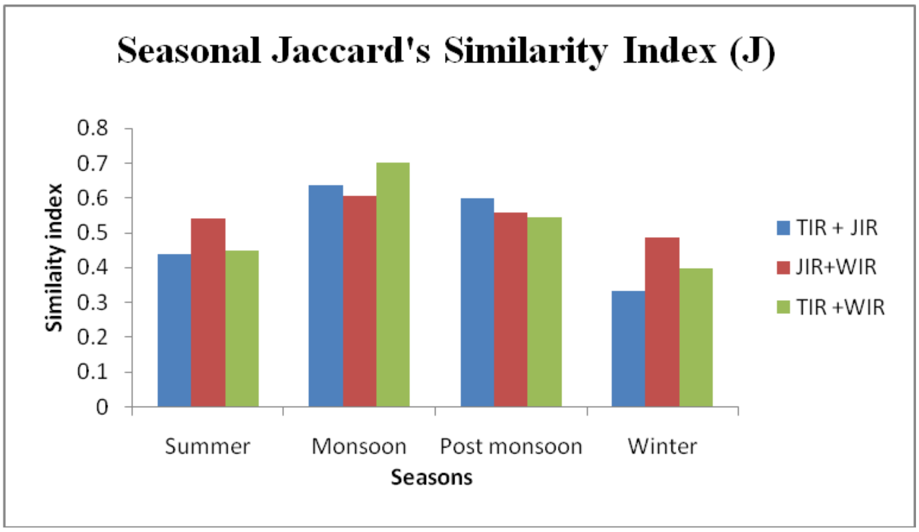
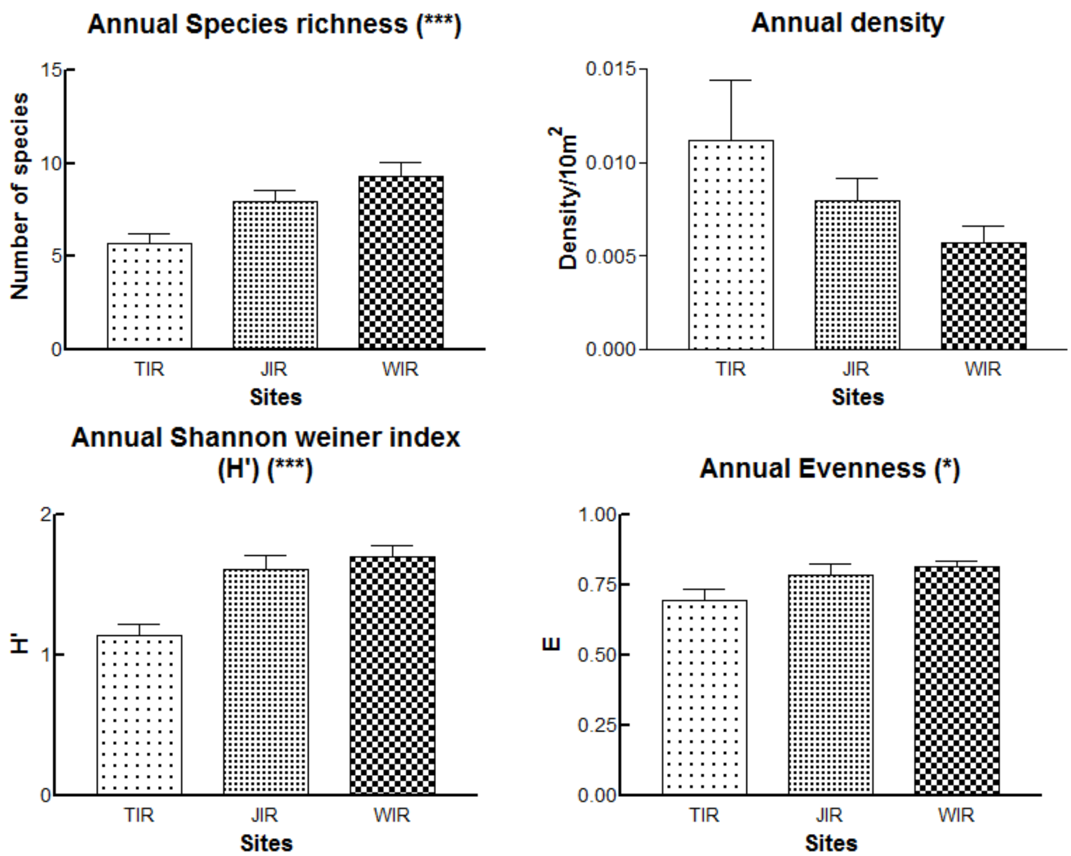
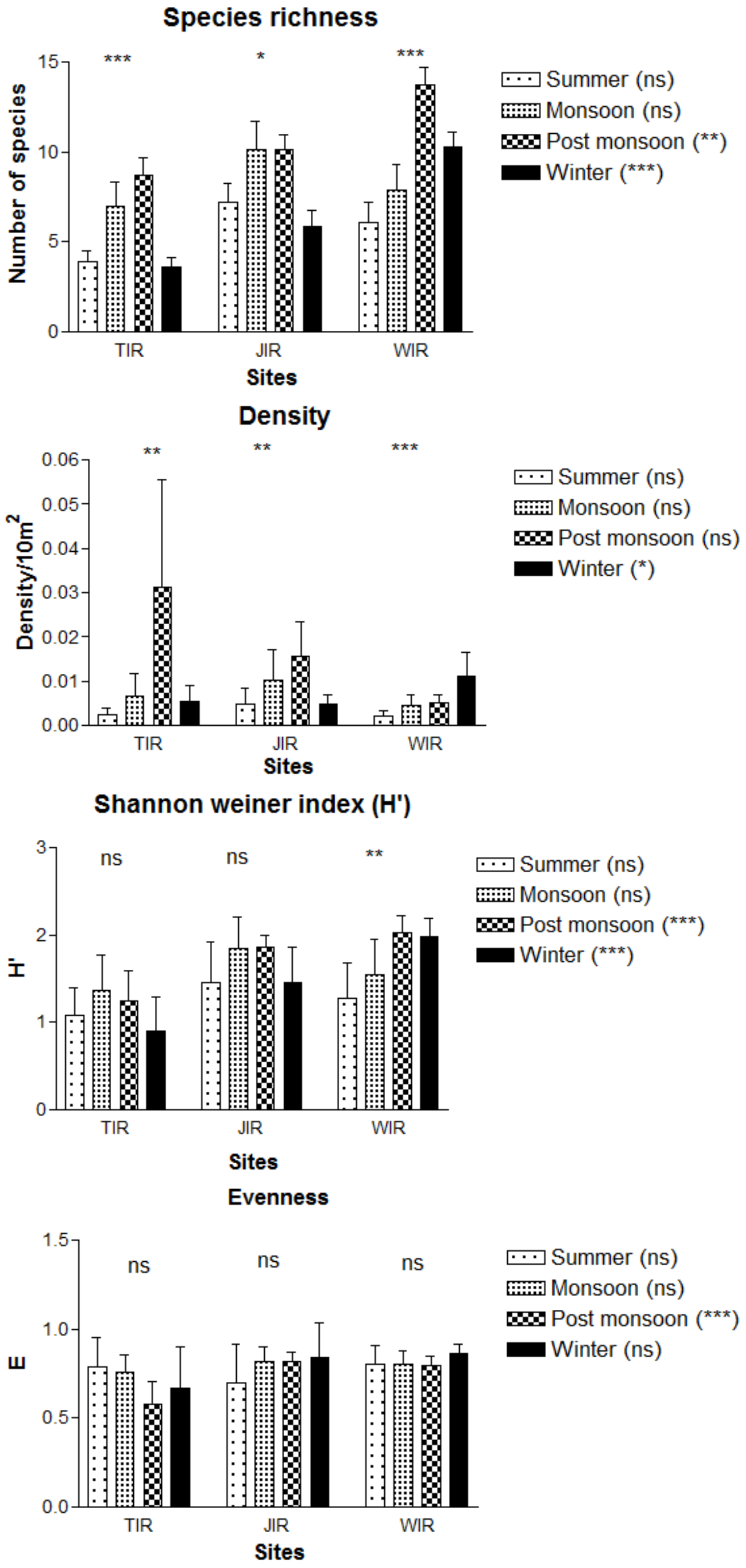


Figure 5.5 : Annual mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of the butterflies at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



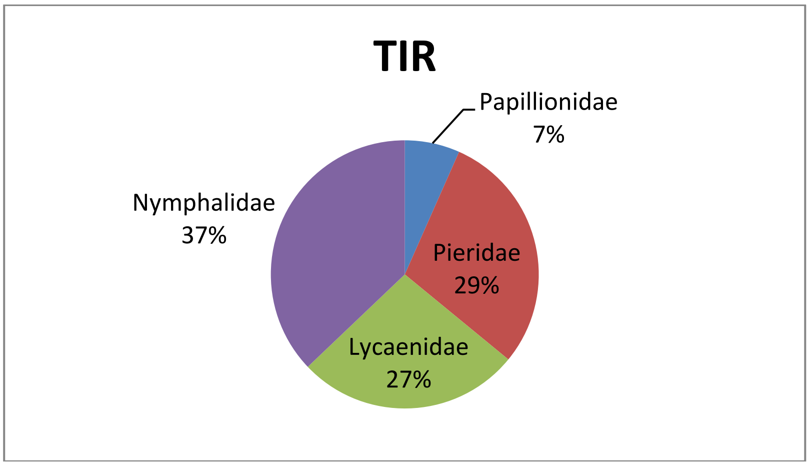
For ANNOVA ns ($P > 0.05$), * ($P < 0.05$), ** ($P < 0.01$), *($P < 0.001$)**

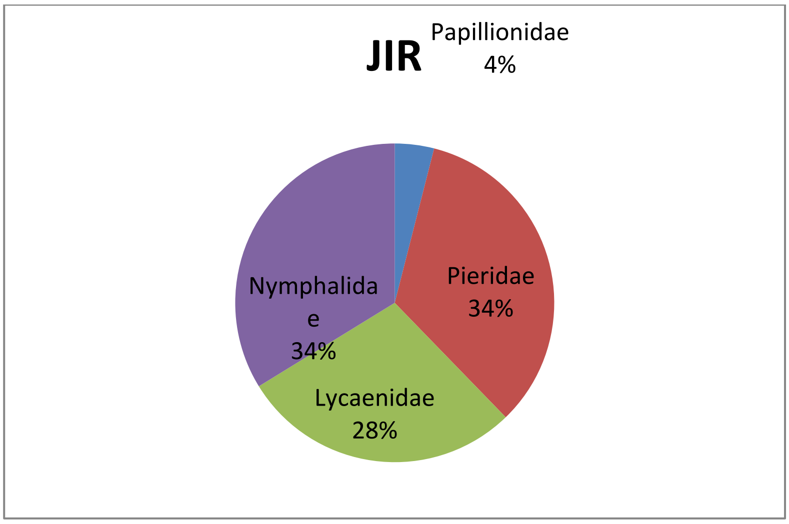
Figure 5.6 : Seasonal variations in the mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of the butterflies at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

Figure 5.7: Annual Percentage Occurrence of the four butterfly families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)





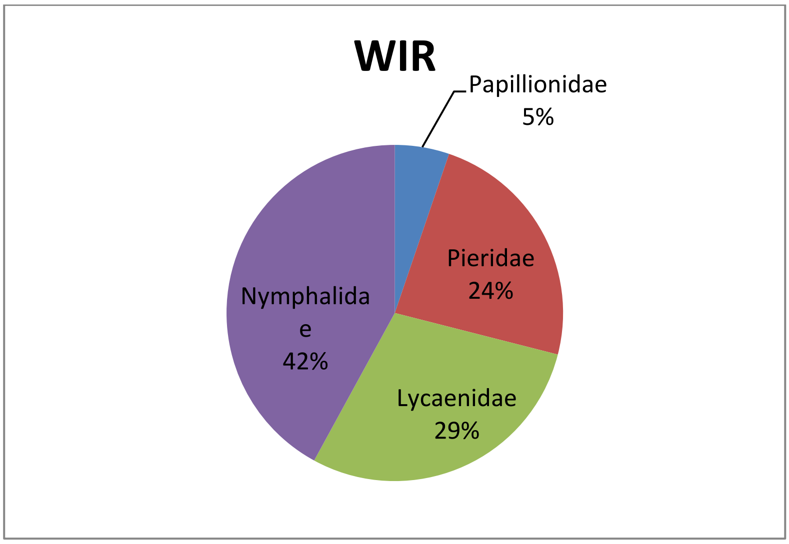


Figure5. 8: Seasonal variation in the Percentage occurrence of four butterfly families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

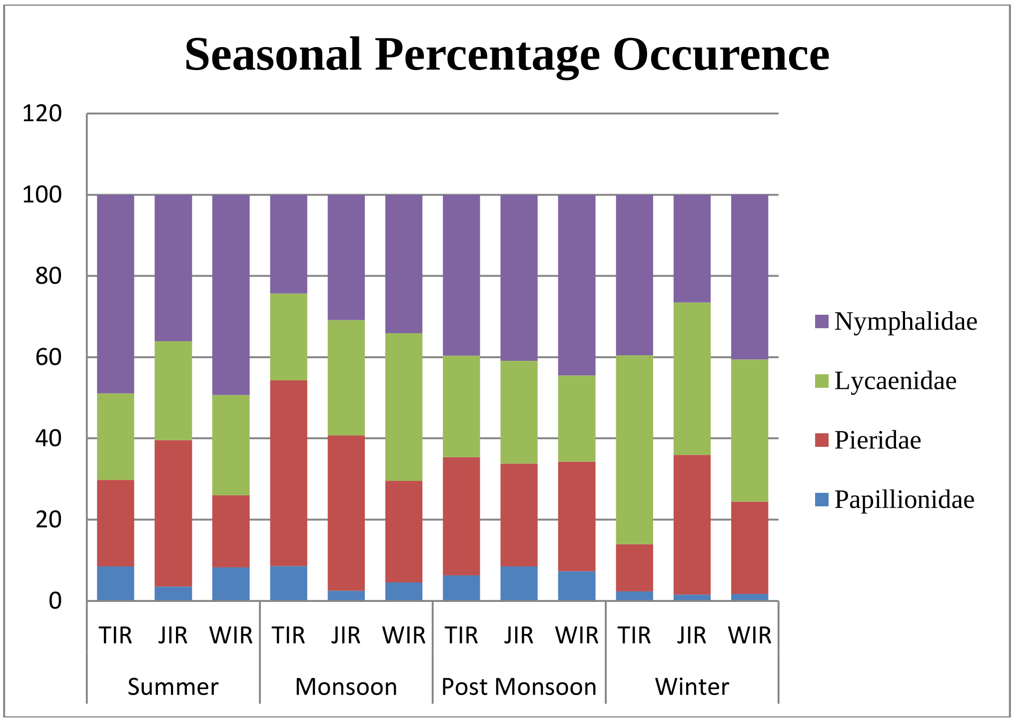


PLATE 10: SOME OF THE BUTTERFLIES OBSERVED IN THE STUDY

Hypolimnus missippus (Danaid Eggfly)

Danaus Chrysippus (Plain Tiger)

Junonia almana (Peacock Pansy)

Junonia orithya (Blue Pansy)

Hypolimnus bolina (Great Eggfly)

Junonia lemonias (Lemon Pansy)

Euploe core (Common Crow)

Danuas genutia (Stripped Tiger)

Eurema hecabe (Common Grass Yellow)

Ixias mariammme (White Orange tip)

Parerona valeria (Common Wanderer)

Catopsilia pomona (Common Emigrant)

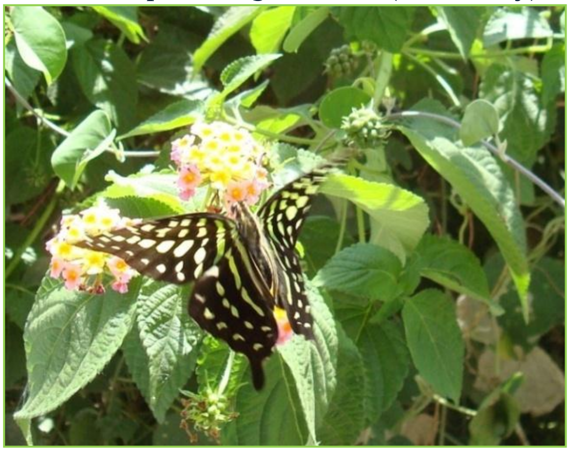
Delias eucharis (Common Jezbel)

Euchryops cnejus (Gram Blue)

Zizina otis (Lesser grass blue)

Lampides boeticus (Pea blue)

Graphium agammnon (Tailed Jay)



Papilio demoleus (Lime butterfly)

DISCUSSION

Five butterfly families represented by 1501 species are recorded from India (Gaonkar, 1996). These are also recorded by Kehimkar (2008) with 107 species of Papilionids, 109 species of Pierids, 443 species of Lycaenids and 521 species of Nymphalids, while the family not recorded in the present study Hesperiidae is represented by 321 species in India. In the present study, of the 49 butterfly species recorded 5 species belonged to Papilionidae, 16 to Pieridae, 10 to Lycaenidae and 18 to family Nymphalidae.

Number of Species

The highest number of species (42) observed at WIR can be due to its large size with several microhabitats providing specific needs of different species. Larger area supports more species (Rosenzweig, 1995; Oertli *et al.*, 2002). In addition, it is also a least disturbed area among the three reservoirs facing low anthropogenic pressures. Many species of butterflies prefer such undisturbed areas (Tiple *et al.*, 2007). Of the other two reservoirs, TIR is the reservoir impacted with higher human activities as well as grazing. It supports more of the generalist species adapted to human activities like gardening and kitchen gardens of the urban areas. When the locations of the three reservoirs are considered, TIR is nearer to the city and also under the pressures of urban expansion with development of the educational institutes as well as farm houses. This increases the probability of the generalist species because of the environment resembling the urban ecosystem. However, around JIR though human activities are slowly increasing more specialist species were noted compared to TIR. This indicates that different species of butterflies do visit dry lands around wetlands and also the habitats under anthropogenic pressures. At such habitats the butterfly may not stay for longer duration but they may appear there during their exploratory visits. The native species mainly prefer natural habitats while those species that adapt to human presence thrive in the areas with anthropogenic influences (Kark *et al.*, 2007).

Species Diversity in different families

Nymphalidae is the most dominant family in terms of distribution and number of species (Dudley and Adler, 1996) and is also thought to be the most ecologically diverse butterfly group (Jiggins *et al.*, 1996). Initially Danidae, Satyridae and Acraeidae were considered as separate families but now these all are considered as the sub families of the family Nymphalidae (Gay *et al.*, 1992) hence all together maximum 18 species belonging to this family were recorded in the present study. These are the most brightly coloured butterflies amongst all the butterflies. This family was found to be dominant in the studies conducted by Sreekumar and Balakrishnan (2001) in the Aralam Wildlife Santuary, Kerala, Hussain *et al.*, (2011) in the DAE campus, Kalpakkam, Tamil Nadu, Rajagopal *et al.* (2011) in the Arignar Anna Zoological Park and Patil (2011) in the Satpuda mountain range. Its occurrence is noted from different types of habitats ranging from protected areas or the campus of major institutes or university campus to the urban areas (Kunte 1997, Devy and Davidar, 2001; Sreekumar and Balakrishnan, 2001; Tiple *et al.*, 2007; Saikia *et al.*, 2009; Raut and Pendharkar, 2010; Tiple and Khurad, 2009; Hussain *et al.*, 2011; Rajagopal *et al.*, 2011; Tiple, 2011). Thus, the dominance of Nymphalidae in varied environmental conditions indicates their preference for varied habitats ranging from the scrubland to secondary vegetation, forest edges and gardens (Larsen 1995). Their dominance has been attributed to their polyphagous habit which helps them to live in all these habitats (Sreekumar and Balakrishnan, 2001). Hence, this was the most dominant family in the present study too.

The first subfamily of Nymphalidae, Danainae, also known as the Milkweed butterflies due to their feeding habits on the members of the plants belonging to family Caesalpineacea and Asclepiadaceae, was the most common, conspicuous and well known group present in the study. This group of butterflies feed on the milkweeds like *Heliotropium indicum* and *Crotalaria verucosa* that are the major source of Pyrollizine alkaloids, which are precursors of Danaid pheromone cum defense chemical called Danaidone (Boppre *et al.*, 1978). This mechanism leaves most of the danaid species unpalatable to vertebrate predators (Dudley and Adler, 1996). These butterflies are found in variety of habitats from wet evergreen forest to scrub, open landscapes, deserts and mountains (Kehimkar, 2008). They are also common in the gardens and urban habitats flying close to the ground. Danaids are known to migrate and roost together in large numbers during winter and summer. Ramesh *et al.* (2010) have reported their highest density in the scrub jungles.

Four species of this sub-family were observed with all species graded differently (*D. chryssippus* –Abundant, *D. genutia* –frequent, Uncommon and rare, *Euploea core* –Uncommon and *Tirumala limniace* –rare) at the three reservoirs. Plain Tiger (*D. chrysippus*) was the most abundant species at all the three reservoirs and also the most common species among whole of the butterfly fauna noted during the present study. It is primarily a butterfly of open country but is seen in forests too, and also up to 2,500 m in the hills (Kehimkar, 2008) and open agricultural lands (Larsen, 1995). It is seen on wings all throughout the year (Kehimkar 2008). The overall dominance of *D. chrysippus* is due to its ability of chemical defense against predation. The larvae of this species often feed on plants containing poisons and unpalatable substances. Being an unpalatable prey species, *D. chrysippus* has greater survival superiority (Ramesh *et al.*, 2010). Further, being migratory species, large aggregations of this species can be found in summer and winter when they are known to migrate.

E. core (Common crow) the second species of this family observed in the present study is categorized under Schedule IV of Wildlife Protection Act (Tiple and Khurad, 2009). According to Joshi (2007) this species is positively affected by the moderate disturbances. *E. core* with *T. limniace* and *D. genutia* are fond of bright sunlight (Mathews and Anto, 2007). These species are also found to feed on the flowers of

Lantana camara, *Cuphea sp*. and *Ixora sp.* As found in the present study, Tiple and Khurad (2009) too found *D. chrysippus* and *E. core* occurring all throughout the year around Nagpur city.

The sub-family Satyrinae was the family represented by only two species. This family consists basically of the Browns which are more frequent during dawn. Many of them live around wetlands like forest streams, swamps, and wet meadows. High abundance of satyrid butterflies in any area has been attributed to the high abundance of the grasses and reeds, which form the major food plants of these butterflies (Arun and Azeez, 2003). Although grasses and reeds are present in and around the wetlands surveyed, satyrids were rare. They are generally weak fliers and often shun bright sunlight hence probably they were not common in the study which was mostly carried out in the sunny hours of the day.

Among rest of the Nymphalid butterflies, Blue pansy (*J. orithya*), Peacock Pansy (*J. almana*), and Danaid eggfly (*H. missipus*) were the common species at WIR, while these were frequently observed at TIR and JIR. *H. missipus* is the species listed in the Schedule I and II of the wildlife protection Act 1972 (Joshi, 2007) which was common, frequent and uncommon around the three reservoirs. Lemon pansy (*J. lemonias*) was one of the frequent species at JIR as compared to *J. orithya* which was uncommon. *J. orithya* prefers disturbed as well as cattle grazed habitats (Kunte, 1997; 2000). The cattle grazing pressure is low around WIR, but due to development of ecotourism the disturbance in the area has probably increased and at TIR grazing is most prevalent among the three reservoirs, hence Blue pansy is one of the common/frequent species at these two reservoirs. Tawny coster (*A. terpsicore*), known to be inclined towards the open plains where there is good intensity of light (Sreekumar and Balakrishnan, 2001), was probably attracted to the open wasteland around WIR and was frequent.

Pierids, the butterflies of family Pieridae, prefer open spaces, gardens, glades, seashores and watercourses. The study areas being dry scrublands around the wetlands are one of the suitable habitats for the pierids. Also called as white butterflies these are the most conspicuous of all our butterflies because of their colour which brightly reflects the sunlight and sheer numbers that make their occurrence extremely common in the gardens. Lush green agricultural matrix in post-monsoon around the three reservoirs were visited by 16 pierids species which frequently visited dam site hence this family had good representation around the three reservoirs. All the 16 pierid species were observed at JIR which has dense vegetation on the earthen dam as compared to other two reservoirs. At TIR and WIR 13 species of Pierids were observed. However, only Grass yellow (*E. hecabe*) was rated as common while rest were either frequent, uncommon or rare. Frequent and uncommon species include Common Jezbel (*Delias eucharis*), White orange tip (*Ixias marianne*), Common emigrant (*Catopsilia pomona*) and Mottled emigrant (*Catopsilia pyranthe*).

E. hecabe (Common Grass Yellow) the most common species of Pieridae in the present study is known to proliferate in all types of habitats and occurs all round the year due to its polyphagous nature (Kunte, 1997; Joshi, 2007). Further, it is reported to be abundant in both disturbed as well as undisturbed habitats (Joshi, 2007), and are the commonest butterflies in the world (Larsen, 1987). Kunte (1997) also reported high population of Grass yellow during major part of the year except spring and summer. They produce broods all throughout the year compared to other species that produce one or two broods per year and disappear for hibernation in winter (Khanal, 2006).

As per the records of Sreekumar and Balakrishnan (2001), *Leptosia nina* and *Catopsilia sp*. are African forms and rest all recorded in the present study belong to the Oriental region. *Catopsilia pomona*, and *Eurema hecabe* are the two species usually most abundant around the stream sides (Vu and Vu, 2011). These two species were present around all the three reservoirs which though permanent water bodies have inlet and outlet canals probably creating lotic type of ecosystem. Further, both *Catopsilia sp*. and *Eurema sp.* are also reported to feed on the flowers of *Lantana camara, Cuphea sp.* and *Ixora sp*. and are also fond of bright sunlight and hence their number are higher during the bright sunny days (Mathews and Anto, 2007). Study areas located in semi arid zone of subtropics receive plenty of sunlight all throughout the year hence can be important habitat for the Pierid butterflies.

Members of next family Lycaenidae prefer to fly in sunshine but usually fly close to the ground. They are found in major biomes and vegetation associations from climax forests to scrublands, grasslands, wetlands, semi arid regions and deserts, consisting a wide range of habitats as well as waste grounds in cities (New, 1993), hence good diversity of Lycaenids was also observed in the present study. However, their abundance varied around the three reservoirs. Among the ten Lycaenids reported in the present study, Grass blues and Gram blue were the most notable species.

Common Pierrot (*Castalius rosimon)* a rare species in the area comes under Schedule I of the Wildlife Protection Act 1972, while Gram blue (*Euchrops cnejus) and* Pea blue *(Lampides boeticus)* under the Schedule II (Tiple and Khurad, 2009). According to Kunte (2001) species of Grass blues are found in a variety of habitats, hence Lesser Grass blue (*Z. otis*) and Tiny Grass blue (*Z. hylax*) were rated either abundant, common or frequent around the three reservoirs due to the difference in the microhabitats. *Z. otis* prefers open habitats with lower vegetation that resembles the scrub grasses present around WIR making them abundant species while *Z. hylax* is a weak flier often flying close to the ground and frequently settling to feed on small flowering plants that are more common around TIR compared to other two reservoirs. As compared to other butterfly families, grasslands and other open vegetation types are vitally important habitats to many members of family Lycaenidae (New, 1993).

Kunte (1997) has observed the presence of Grass blues and Grass jewel at the site with the grazing pressures. Many Lycaenid caterpillars, including those of Grass blues and Gram blues are among the most common Lycaenid species feeding on low-growing herbs, especially papilionaceous herbs (Kunte, 1997). Caterpillars of Grass jewel (*Chilades trochylus*) and Gram blue (*Euchrops cnejus)* feed on flowers and pods of such herbs (Kunte, 1997). Many of these butterflies appear in late monsoon and reach a peak density in winter. In the present study also more Lycaenids were observed from Post-monsoon to winter.

Other Lycaenids observed includes *Tarucus indica* and *Everes lacturnus* which were frequent at one of the three reservoirs. *T. indica* is a species preferring to fly on low grasses and low growing flowers. The grasses surrounding the dam serve as good microhabitat for this species. Its caterpillars show a unique quality, as they are attended by ants, so the selection of the food plants by the caterpillar depends on the presence of ants on the plants (Kehimkar, 2008). As discussed in Chapter 6 more ants were observed on the bushes at JIR hence this species was frequent there. *E. lacturnus* mostly prefers the hilly habitats and sometimes is observed in the plains on the grassy patches flying in sunshine (Kehimkar, 2008). This species is mostly active during the hot and wet season of the year. It was observed to be a frequent species at WIR which is as said earlier, is a larger reservoir providing varied types of microhabitats as compared to the other two.

Swallowtails, the Papilionids, are mostly tropical butterflies preferring open areas (fields, vacant plots, meadows, open forest, sides of the streams, *etc.*). They are mostly found in the forests and at few instances around the swamps. Mathews and Anto (2007) have reported that area having tall native trees providing cool shade mixed with sunlit patches is one of the favourable habitats for several papilionids. Shaded areas mixed with proper sunlight are not at all available around the three reservoirs of semi arid zone of Gujarat, India, hence a low diversity of Papilionids was observed here. All of them are generalist species basically preferring urban habitats near gardens where their food plants (Ornamental flowering plants) are available. Of the 5 species of Papillionids observed around the three reservoirs, Lime butterfly (*Papilio demoleus*) and Common Rose (*Atrophaneura aristolochiae*) are rated as Uncommon while other three species as rare. Lime butterfly (*P. demoleus*) and Tailed Jay (*Graphium agammnon*) were observed at all the three reservoirs. *P. demoleus* is the most widely distributed swallowtail in the world because of its capacity to adapt to diverse habitats. Its larvae is an invasive pest species (Lewis, 2009) of citrus plants preferring habitats near stream and riverbeds (Kunte, 2000). In the study conducted by Tiple and Khurad (2009) *P. demoleus* was a common species found all round the year. Proliferation of *P. demoleus* has been considered to be aided by agricultural land use and urbanization that creates new, suitable open habitats and enhances the availability of host resources (Lewis, 2009). Hence, though uncommon it was present in the study area. *G. agammnon* a rare species of the area is known to be favoured by the woodlands where rainfall is heavy (Kehimkar, 2008). However, it is seen in gardens in urban areas due to abundance of its food plants. Common Rose (*A. aristolochiae*) is a generalist species adapted to a wide range of habitats ranging from the Western Ghats to the Himalayas and northern plains to the southern plateaus in India. It is also one of the abundant species of the gardens and found easily in the crowded urban areas. It becomes active from early morning and is seen flying whole day and hence it was observed occasionally at TIR and WIR but was not observed around JIR. It is also one of the commonest of the swallowtail butterflies in India. It feeds on the plants of family Aristolochiaceae which produce the toxic aristolochic acid which makes this species unpalatable for large number of higher organisms. Crimson Rose (*Atrophaneura hector*) is another unpalatable papilionid common in the Western Ghats up to Maharashtra but is rare in Gujarat. It prefers forests and open country but was observed at TIR accompanied by A. *aristolochiae*. This species is known to roost in large numbers with *A. aristolochiae* and *Papilio polytes* due to the resemblance in their morphology. Common mormon (*Papilio polytes)* though one of the common papilionid of India was observed only once during the study in month of September. Its female is known to mimic *A. aristolochiae* to avoid predation. It prefers wooded country and is found near the Orchards of lime and oranges. This species was observed at WIR which has a little patch of the tall trees which may have appeared as the woodland for this species. This species is known to prefer monsoon and post-monsoon over other parts of the year. Most of the butterflies are favoured by rainfall or onset of monsoon and are more frequent during the wet season of the year.

Members of family Hesperiidae are not the true butterflies and are stout dull coloured insects. These are often mistaken as moths and many researchers consider them as the connecting link between the true butterflies and moths (Kehimkar, 2008). These are known as skippers due to their rapid erratic flight. Most of the Hesperids either fly during early hours at dawn or in the evening at the dusk, hence probably they were not observed.

Jaccard's Similarity Index

75% of the butterfly species common between TIR and JIR, and 65% between TIR and WIR as well as JIR and WIR suggest the similarity in the macro-habitat around the three reservoirs. All the three reservoirs are located in the semi arid zone of Vadodara District within a diameter of 50 Kms. Hence, major differences in the environmental factors were not noted due to the close locations leading to significantly high similarity. However, the highest similarity noted between TIR and JIR can be mainly attributed to the presence of the generalist species at both the reservoirs compared to the presence of some of the specialist at WIR alone.

When the seasonal similarity is considered, the highest similarity in monsoon can be mainly due to the fact that rainfall acts as precursor for many species (Wolda, 1988;

Sabu *et al.*, 2008; Anu *et al.*,2009) and hence their number increases with the onset of monsoon. During monsoon due to rainfall the vegetation grows that creates better opportunities with the availability of the food plants for the phytophagous larvae as well as nectar for the adult butterflies. However, the absence of specialist species at WIR in this season resulted in the higher similarity between TIR and WIR. Comparatively moderate but same similarity index during post-monsoon indicate the presence of many different species at three reservoirs. Due to the presence of large amount of food plants in wide variety of habitats the chances of the dispersion of certain species is possible ultimately reducing the similarity index. Winter is not a favourable season as low temperatures makes survival of many species difficult reducing their number ultimately leading to the low species richness and low similarity. However, good similarity observed between JIR and WIR can be attributed to the comparatively high generalist species observed during the season at both the reservoirs. In summer also the similarity was low as this is also an unfavourable season due to the higher temperatures recorded. However, the number of species during this season was comparatively higher due to the moderate temperatures of March, the Indian spring, when many flowers are blooming increasing the food resources. This can be a second peak for several species of butterflies. The highest similarity in this season was observed between JIR and WIR suggesting the similarity of the micro-habitat with no urban influence.

Annual Differences

Mean Species Richness

As mentioned earlier in the chapter, larger area supports more number of species (Rosenzweig, 2005; Oertli *et al*., 2002). Larger habitat, WIR provided variety of microhabitats for the butterflies to explore and hence maximum species richness was recorded. *Vice -a- versa* it can be said that smaller area will support lower number of species as is noted for TIR where lowest species richness was recorded. In addition, at

TIR anthropogenic activities are also more and hence probably least explored habitat by specialist species of butterflies. JIR also had good species richness due to the presence of bushes as well as trees in the vicinity of the reservoir.

Mean Density

As is mentioned in chapter 1, the opposite or the converse results to that of species richness were observed for density in the terrestrial habitat where, with the increase in the area the density present in the area decreased. This probably resulted due to dispersion of the species over a larger space. As more microhabitats are available at WIR the species shift to the favourable habitat ultimately leading to lower density. On the other hand, TIR had smaller area where the species could not get more space to wander and hence gathered in small area increasing the density. At JIR the butterfly density was found to be moderate as they got good resting places at this reservoir where the vegetation is denser compared to the other two reservoirs.

Mean Diversity index and **Evenness**

The values of H' and evenness are interrelated. The highest H' and Evenness recorded at WIR while lowest at TIR are indirectly related to the species richness of the area. The higher the species more are the chances of the population to be uneven. A population that has species with more or less same number of individuals has higher diversity index as well as higher Evenness. The species observed at WIR did not vary largely in the numbers leading to the higher H' and Evenness while at TIR the number of species was low and each were represented with vast differences in the number of individuals. In case of JIR all the four diversity parameters were intermediate towards upper level.

Seasonal Differences

Species Richness

Almost all butterflies show seasonal trends (Kunte, 1997) and have short seasonal peak. Rain acts as the precursor (Wolda, 1988; Anu *et al.*, 2009) for majority of the butterflies leading to their appearance after the hot dry summer. The wet season favours the growth of their larval food plants aiding increase in their density as well as diversity. However, the highest species richness not observed in monsoon can be mainly attributed to the late onset of the monsoon during the study period where the rainfall started approximately in mid July and the earlier period had higher temperatures which probably did not favour the butterflies. After the onset of monsoon slowly the species started exploring the habitats and maximum species richness were observed during post-monsoon when all the necessary requirements favouring butterfly population were at their best. The varied species present got more area for hiding and hence could shun predation. At JIR, the species richness was recorded to be constant in monsoon and post-monsoon suggesting the minimal changes in the habitats during these two seasons of the year.

In winter due to the fall in the temperature the conditions become unfavourable for survival of this poikilothermic organisms and hence many butterflies over winter to avoid the hostile conditions (Dvořák *et al*., 2009) reducing the species richness. The high species richness at WIR could be due to the presence of dense vegetation in certain areas around the reservoir which provided more area for the butterflies to hide in the cold climatic conditions. In summer, due to the high temperatures, again butterflies were not observed leading to their low species richness. However, at TIR and JIR the species richness was almost maintained during the harsh seasons when only year round species were noted.

When the three habitats are compared it was found that TIR was inhabited by minimum species all throughout the year. This may be due to the habitat being influenced by the human activities, cattle grazing and fishing that creates disturbances and do not allow the colonization or the exploration of the specialist species that require particular set of conditions. Here, the species present are mostly the urban or garden species that are habituated to disturbances caused by humans. The highest species richness among the three reservoirs recorded in summer and monsoon at JIR can be accredited to the presence of more vegetation on the dam as compared to other reservoirs. Here a patch of trees is present on the dam which is not pruned increasing the shade cover as well as surface area for resting. At other two reservoirs no tall vegetation is present in the immediate environs and whatever is present is removed in summer as part of management practice. This reduces the resting places for butterflies in hot summer. During monsoon, the rains restricted the movement of the butterflies. Post monsoon being the most favourable season when all the climatic conditions are moderate majority of species emerge and exhibit flight period. Another factor influencing the higher species richness at WIR compared to other two reservoirs is the presence of more microhabitats due to larger area. On the other hand the high species richness during winter at WIR among the three reservoirs can be attributed to the presence of the dense vegetation in the region between the reservoir and the agricultural fields which rejuvenated due to the preceding monsoon. This vegetation provides good habitat for the butterfly exploration leading to their higher species richness.

Density

The seasonal density showed great variation at the three reservoirs. Kunte (1997) has reported that butterfly population starts building up in early monsoon and shows first peak in late monsoon which may be considered as the post-monsoon in the present study while the second peak is observed in winter. Hence, in the present study, butterfly population was observed to build up during wet season as well as in dry cold season while in the dry hot season, summer, butterfly population declined. These results are in accordance with results of Pandharipande (1991), Kunte (2001), Tiple *et al*. (2007), Arun (2008), Tiple (2009), Hussain *et al.* (2011). The increase in population during post-monsoon and winter can be due to prevalence of the favourable climatic conditions along with availability of the food resources for the adult as well as larvae. Nevertheless as noted for species richness the density was also recorded to be lowest during winter at TIR and JIR because lower temperatures restrict the movements of many butterfly species. At WIR the dense vegetation between the dam and agricultural fields along with dense vegetation towards eastern side of reservoir increased the warmth in the area producing a favourable microclimate for butterflies to hide and come out only when sun is high in the sky. Lowest density was recorded in summer for all the reservoirs as the temperature are high and the vegetation is sparse, an unfavourable condition for most of the insects.

The presence of more shade as well as resting places at JIR resulted into highest butterfly density among the three reservoirs during summer and monsoon in comparison to the dry and cleared vegetation at the other two reservoirs. The highest density noted at TIR during post-monsoon could be accredited to prevalence of generalist species in high number due to favourable climatic conditions. During this season the disturbances at the reservoir are also low due to the availability of water as well as grass everywhere. As said earlier during winter the density was highest at WIR as butterflies got shelter in the dense vegetation. Another reason for the increase may be the local migration of some individuals from the reservoir due to the unfavourable conditions prevailing in the surrounding semi-arid zone.

Shannon Weiner Diversity index H' and Evenness E

The Diversity index and Evenness also showed the same trend as that for Species richness and density at WIR with the higher values in post-monsoon and winter. At WIR H' followed the same trend as species richness indicating that post-monsoon followed by winter are the best seasons for butterflies around WIR. At other two reservoirs the higher diversity index was observed from monsoon when the species richness was also high leading to the low chances of the sudden increase of any single species. Among these two reservoirs, at JIR the H' was almost same in monsoon and post-monsoon indicating that favourable season starts earlier at JIR. However, at the other reservoir, TIR though the species richness and density of butterflies increased in post-monsoon H' and Evenness declined indicating uneven distribution with respect to generalist and specialist species as most of the species were present for only certain time period and disappeared during other part of the season.

Evenness showed maximum variations at TIR while at other two reservoirs it varied in a narrow range. As discussed earlier, the higher variations in the Evenness at TIR is mainly attributed to the fluctuations in the density of various species during different seasons of the year while at JIR and WIR, whichever species were present, always had more or less even distribution. Evenness also depends on the habitat composition, change in habitat composition is expected to affect the presence of certain species ultimately influencing the species distribution in the area. This was evident at TIR where due to human activities as well as grazing, changes in the habitat are noted.

Evenness showed no difference during summer and monsoon when the species present were more or less equally distributed leading to high evenness as is reflected at all the three reservoirs. At TIR very high density of Tiny Grass blue in post-monsoon of first year and that of Common Grass yellow in second year lead to the uneven distribution of the species and decline in the evenness resulting in the significant differences among the three reservoirs. Contrarily, the evenness at JIR and WIR was almost constant all over the seasons. During winter the evenness differed non-significantly as the differences among the three reservoirs were minor.

Annual Percentage Occurrence

Percentage occurrence is the comparative mathematical measure wherein the increase in the percentage of one family influences the other by decreasing its percentage. At all three reservoirs the highest percentage occurrence of Nymphalidae suggests that it is the most dominant family in the area. Several studies report higher percentage of

Nymphalidae (Kunte 1997, Devy and Davidar, 2001; Sreekumar and Balakrishnan, 2001; Tiple *et al.,* 2007; Saikia *et al.*, 2009; Raut and Pendharkar, 2010; Tiple and Khurad, 2010; Hussain *et al.,* 2011; Rajagopal *et al.,* 2011; Tiple, 2011). However, at JIR Pieridae also had the same percentage occurrence as that of Nymphalidae suggesting the suitability of the habitat for either of the families. As said earlier Pierids are the sun lovers and are more frequent in the sunlit areas where they can bask, JIR has more vegetation where these could easily bask and hence higher percentage occurrence of the family. At TIR too, Pierids had good percentage occurrence. However, at WIR it was Lycaenidae – the blues. Lycaenids prefer short grasses that are most often present at WIR all throughout the year except summer when the vegetation is removed. Papilionids had lowest percentage occurrence in the present study as most of the species of this family are the species preferring to live in the undisturbed and dense vegetation of the forests. In addition, most of the papilionids feed on the members of the family Rutaceae which were not present around the studied reservoirs; hence the lack of food plants in the area resulted in the low percentage occurrence of the Papilionids around the three reservoirs.

Seasonal Percentage Occurrence

The seasonal percentage occurrence of the butterfly families also showed the overall dominance of family Nymphalidae but Lycaenidae and Pieridae were also the dominant families during some season of the year. The dominance of the butterfly families greatly depend on the habitat available. Among the three reservoirs, most varied habitat was available at WIR which resulted in the presence of different families during different seasons of the year.

Nymphalidae is the largest butterfly family as the recent phylogenetic classification has merged large number of other families considered as separate families earlier in to it. Now the Nymphalidae includes Milkweed butterflies, Browns, Heliconians and Beaks.

Some nymphalids are good fliers involved in the migration while others like Satyrinids-the Browns are weak fliers. As many sub-families constitute this family, Nymphalids has a diverse preference of habitats ranging from the high altitudes, forests to the scrubs and the open countries. Due to their ability to live in wide range of habitats this family has explored all the habitats and is most common of all the butterfly families. In the present study the highest percentage occurrence of this family in summer is mainly attributed to the presence of the Plain tiger along with the pansies. During post-monsoon almost all Nymphalid species were observed due to the presence of favourable climatic conditions. Plain tiger and Blue pansy of Nymphalidae occurred in higher numbers at WIR whereas Peacock Pansy and Plain tiger at TIR, while Plain tiger and Lemon pansy at JIR. As discussed earlier, Plain tiger is one of the most common butterfly of India found in all types of habitats and in all seasons (Tiple *et al.*, 2007). Because of their unpalatable nature, Danaid butterflies are known to colonize well and are not afraid of coming out and flying leisurely. As post monsoon is a favourable season overall population of the butterflies is high and hence Nymphalids were recorded with highest percentage. At WIR, in winter too this was the most dominant family due to the presence of the species like Tawny coster, Pansies and all the Danaiids.

During Monsoon, the conspicuous wet season, Pieridae dominated at TIR and JIR. This may be due to the wet season forms of family Pieridae which are easily observable. Most of the Pierids have dry season forms and the wet season forms, the latter are more prominent in features and hence they can be easily observed as compared to the others. The high total percentage occurrence of the Pierids can also be due to presence of Grass yellow (*E. hecabe*) which is much more conspicuous in monsoon compared to other seasons of the year. This species visits not only flowers but also damp patches (Kehimkar, 2008) and was more common in monsoon. Other reason for its higher occurrence was the availability of one of its favourable food plant *Acacia* at all the three reservoirs. In case of JIR, White Orange tip was also observed during all the visits in monsoon. The increased prevalence of this species during monsoon may be its preference for the damp sites and its habit of flying after the rains. The lower percentage occurrence of this family at WIR can be attributed to the higher percentage of the other groups as the percentage occurrence is a comparative expression. Pierids were also present at WIR, but the Lycaenids were more in number compared to this group and hence lower percentage of Pieridae during monsoon at WIR.

Lycaenidae consists of various blue butterflies that prefer short grasses and shun sunlight by hiding in the grasses. The grasses growing in monsoon attracted them and they showed the highest percentage in monsoon at WIR. As many of these butterflies are herb feeders and smaller in size they were found to be the dominant family during winter at TIR and JIR where small grasses and herbs are present when the vegetation slowly starts drying and hence is not preferred by other large butterflies. According to Kunte (1997) the dominance of Lycaenids in late winter may be the result of the resource based inter-specific competition for nectar sources in the adult butterflies. Larger butterflies which are non herb feeder dominate in the early season and push the smaller herb feeders to survive towards the end of the favourable season.

In the seasonal percentage occurrence too, Papilionidae had the lowest percentage occurrence at all the reservoirs in all the seasons of the year. This is because the overall number of species belonging to Papilionidae is low. Most of the Papilionids are forest dwellers and move out only if their food plants are available in plenty as is found for the Lime butterfly. This butterfly has become common in the urbanized area where increased plantation of the citrus plants in the urban gardens as well as kitchen gardens is popular.

Conclusion

It can be concluded from the present study of the butterfly fauna around the three reservoirs in the semi arid zone of Central Gujarat that the scrublands around reservoirs serve as one of the good microhabitat for butterflies. As Butterflies have adapted to large variety of habitats and minor differences in their morphological characters are noted depending on the different habitats they colonize, they are one of the important groups in the ecological studies. Their presence in any habitat can be considered as a symbol of the healthy ecosystem. The good diversity reported in the present study proves that scrubland around reservoirs could also serve as an important habitat for this group of insects.

HYMENOPTERA DIVERSITY AROUND WETLANDS

Introduction

Hymenoptera principally includes holometabolous insects like Ants, Bees and Wasps that undergo complete metamorphosis (egg, larva, pupa and adult). This is the only order besides Isoptera wherein several species exhibits well-organized social systems and members are divided into caste system like worker, soldier, drone and queens. This order is divided into two 2 sub orders Symphyta and Apocrita. Most of the ants, bees and wasps belong to Apocrita while the Symphyta include the primitive hymenopterans like the saw flies, horntails and wood wasps.

Hymenopterans are also ecologically significant as predators, pollinators, parasitoids or even pests as well as biological control agents. Most of the primitive species of this order are herbivorous, some wasps are predators while most of the bees are nectar and pollen feeders aiding in the process of pollination. Ants are the hymenopterans without stings while most of the wasps and bees possess stings.

These eusocial insects; ants, bees and wasps; are excellent subjects for analysis of geographic patterns of species richness (Kaspari *et al.*, 2000; Longino *et al.*, 2002). Among these, ants have achieved unprecedented ecological success and dominance in tropical ecosystems (Gadagkar *et al.*, 1993). They are also bio-indicators, efficient invaders and colonizers of new habitats (Holway *et al.*, 2002) and thrive well in the same. Ants constitute a large amount of animal biomass on the Planet (Folgarait, 1998; Chavhan and Pawar, 2011). They are abundant and ubiquitous in both disturbed and undisturbed habitats and respond quickly to the environmental variables (Majer, 1983; Andersen, 1990; Hoffmann *et al.*, 2000). Ants are ecologically important for soil turnover (Lobery de Bruyn and Conacher, 1994) as well as nutrient recycling (Lal, 1988) and hence considered as ecosystem engineers (Folgarait, 1998; Chavhan and Pawar, 2011). Approximately 60% of the ant species that are currently known, live in leaf litter, where the ant fauna is especially diverse taxonomically, morphologically and ecologically (Silva and Brandao, 2010; Silvestre *et al.*, 2012). All the known species of ants belong to the same family Formicidae and are social in habits (Gadagkar *et al*., 1993).

Importance of ants has been described by Holldobler and Wilson (1990) as ``Ants are everywhere, but occasionally noticed. They run much of the terrestrial world as the premier soil turners, channelers of energy and dominatrices of the insect fauna. One third of the entire animal biomass of the Amazon rain forest is composed of ants and termites, with each hectare of soil containing in excess of 8 million ants and 1 million termites." Hence, ants are one of the prominent invertebrate groups useful in assessing ecological responses to disturbance (Rosenberg *et al.*, 1986; Andersen, 1999; Taylor and Doran, 2001; Andersen *et al.*, 2004; Underwood and Fisher, 2006). As mentioned earlier, they are ubiquitously abundant and important in terrestrial ecosystems, can easily be sampled as they form stationary colonies, their community dynamics varies in relation to environmental stress and disturbances (Majer, 1983; Greenslade and Greenslade, 1984; Andersen, 1990; Yek *et al.*, 2008) and are one of the most commonly studied terrestrial invertebrate (Longino *et al.*, 2002). They have been used as bio-indicators in Australia since long (Andersen and Majer, 2004), and as their presence is correlated with the presence of other organisms they estimate the overall health of an ecosystem (Daniels, 1991; Andersen *et al.*, 2004). Thus, ants form an important taxon for comparing habitat diversity and monitoring environmental changes, because they have habitat preferences and respond quickly to the slight changes in the environment (Anderson, 1990; Alonso *et al.*, 2000; Kaspari and Majer, 2000). Of the many beneficial role played by ants for human being, suppression of pest population as well as erosion of the soil are important (Chavhan and Pawar, 2011).

Bees and wasps also comprise an important group of hymenopterns as pollinators as well as potential controllers of insect pests (Michener, 1979; 2000). Variations in the diversity of these species can be related to the changes in the structure and abundance of their floral and nesting resources (Gess and Gess, 1991; Samejima *et al.*, 2004; Lassau and Hochuli, 2005; Potts *et al.*, 2005; Loyola and Martins, 2008).

Bees are categorized as solitary (Stingless Bumble bee *Bombus sp*. and Carpenter Bee *Xylocopa sp*.) and Colonial forms (Honey Bees *Apis sp*. whose soldiers have stings). In natural ecosystems several plant species depend on bees for pollination (Bawa, 1990; Corlett, 2004) and hence the extinction or the decline in population of these species can even lead to the extinction of such plants. The Carpenter bees are prominent component of Indian bee fauna that occur throughout the year and forage on a wide array of flowers during the day time and sometimes even during moonlit nights. These bees of genus *Xylocopa* collect pollen from nectar less flower while nectar from nectariferous plant species (Raju and Rao, 2006).

Honey bees of this order are the most beneficial species of Class Insecta as they not only produce honey and bee wax but are also potential pollinators mainly of the field and orchard crops (Shruthi *et al.*, 2009). The caste systems in their colony consists of workers, soldiers, drones and a single Queen. The workers are the main foragers involved in pollination and one third of the plant derived food is attributed to the pollination by the honey bees (Williams 1996; Richard, 2001; Klein *et al*., 2007). They are able to exploit wide range of flowers as adults themselves feed on nectar while they feed their larvae with the pollens (Shruthi *et al.*, 2009). The food limitation, nest predation and the spatial dispersion of forage plants, nesting sites and nest building substrates are the important factors influencing population size and reproduction of the honey bees (Deslippe and Savolainen, 1994; Westrich 1996; Eltz *et al.*, 2002). Amongst the numerous kind of bees found in India, the typical honeybees which are social in habits comprise five species, *viz*. *Apis dorsata*. F. (Rock bee), *A. indica*. F. (Indian bee), *A. florae*. F. (Little bee) and *Melipona iridipennis,* Dal. (Dammar bee) (Padmalatha *et al.*, 2007), and *A. mellifera* (European bee).

The other species of Hymenoptera, the wasps are specifically the bio-control agents, important for control of the insect pests. They can be broadly classified as Solitary and Social wasps. All individuals of solitary wasps are fertile and move alone whereas social wasps have the caste system wherein sterile female workers are engaged in collection of food, nest building, *etc*. while the Queen and Drones are fertile and only reproduce. Most of the Social wasps belong to the family Vespidae. Eighty two species belonging to nine genera of social wasps have been recorded from India (Gupta and Das, 1977). Wasps may be omnivorous or parasitic *i.e.* solitary wasps and nectar feeding *i.e.* social wasps. However, most of their larvae feed on insects paralyzed by the parents. Among different types of wasps, paper wasps are believed to influence many terrestrial species in tropical ecosystems (Kumar *et al.*, 2009). They are basically the predators of many other insects and invertebrates (Wenzel 1998; Richter, 2000). These groups also act as important food resource for army ants as well as some of the insectivorous birds (Windsor, 1976; Chadab, 1979, Kumano and Kasuya, 2006). However, Vespid community ecology is poorly studied (Jeanne, 1991).

While studying different insect groups around the three reservoirs, Hymenoptera was found to be a major order and hence is considered in detail here.

Results

The habitat around the three reservoir supported good diversity of Hymenopterans.

Number of Species (Table 6.1, Figure 6.1, Annexure 2)

Total 36 species of Hymenopterans belonging to six families - Formicidae, Vespidae, Sphecidae, Chrysididae, Xylocopidae and Apidae all belonging to sub-order Apocrita were observed around the three reservoirs. Highest 25 species belonging to all six families were present at WIR, while at TIR and JIR 20 and 23 species respectively belonging to five families each were present. Family Chrysididae was not recorded at both TIR and JIR. Among all the families, maximum numbers of species (20) belonged to Family Formicidae, 7 to family Vespidae, 4 to Sphecidae, 1 each to Chrysididae and Xylocopidae and 3 to Apidae. Of the total 20 species of ants, maximum 14 species were present at WIR, while 12 and 11 around TIR and JIR respectively. Common ants encountered include *Oecophylla smaragdina, Monomorium minimum, Componotus compressus, Solenopsis invicta and Tetraponera rufonigra* while rests of the ants were occasionally observed. 5 species of Vespidae were present at JIR and WIR each, while 3 around TIR. *Ropalidia marginata* was the most common species of the wasp encountered in the present study. Of the other 4 species belonging to Sphecidae, 2 species, *Sphex lobatus* and *Sphex sp. 1* were present at TIR, 3 species at JIR and a single species at WIR. A single species of family Chrysididae *Chrysis sp.* was present at WIR while a single species of Xylocopidae (*Xylocopa aestuans*) and 2 species of Apidae (*Apis dorsata* and *Bombus psythrus*) were present around all the three reservoirs. The Metallic green bee - *Agapostemon virescens* of family Apidae was present at the two reservoirs with major agricultural matrix, *i.e.* JIR and WIR.

Abundance rating (Table 6.2, Figure 6.2, Table 6.8)

When the Hymenopterans are rated for their abundance it was found that very few species are either abundant or common while nearly 50% of the species were rare. *Camponotus compressus* was the species rated as abundant at all the three reservoirs while additional two species, *Monomorium minimum* and *Bombus psthyrus* were abundant at WIR. The latter two species were common at TIR and JIR. In addition, at TIR *Oecophylla smaragdina*, *Solenopsis invicta* and *Camponotus sericeus* and at JIR *Tetraponera rufonigra and Xylocopa aestuan* were common. At WIR only two species *Solenopsis invicta and Componotus sericeus* were common. At TIR none of the encountered species was rated as frequent while at JIR 4 species and at WIR 5 species were frequent. These include *Camponotus sp*.1 and *Ropalidia marginata* frequent at both, while *Camponotus sericeus* and *Solenopsis invicta* at JIR and *Oecophylla smaragdina, Apis dorsata and Xylocopa aestuans* at WIR. 2 species each at JIR and WIR and 3 species at TIR were uncommon while the rare species numbered 11 at TIR, 12 at JIR and 13 at WIR.

Jaccard's Similarity index (J) (Table 6.3)

The **annual** Jaccard's similarity index was 0.41 between TIR and WIR, 0.54 between TIR and JIR and 0.55 for JIR and WIR (Figure 6.3). The **seasonal** similarity index was noted to be highest during post-monsoon for all the reservoirs with 0.64 between TIR and JIR, 0.61 between TIR and WIR and 0.71 between JIR and WIR. The lowest similarity was recorded in summer with 0.36 for TIR and JIR, 0.39 for TIR and WIR and 0.41 for JIR and WIR. During monsoon the similarity was noted to be 0.44, 0.37 and 0.67 for TIR and JIR, TIR and WIR, and JIR and WIR respectively. In winter similarity index was noted with 0.52 for TIR and JIR, 0.45 for TIR and WIR, and 0.57 for JIR and WIR. When the comparison is made at a single reservoir during different seasons, increase from summer to post-monsoon and a decrease in winter was noted in similarity index for TIR and JIR as well as JIR and WIR, while for TIR and WIR the similarity was nearly same during summer and monsoon with increase noted in post-monsoon which decreased in winter. The highest numbers of species were common between JIR and WIR in all the seasons while least between TIR and WIR. (Figure 6.4)

Annual Differences in the Mean Species Richness, Density, Shannon Weiner Diversity index (H') and Evenness (E) (Table 6.4, Figure 6.5)

Species Richness –Annual mean species richness of Hymenoptera was maximum 6.79 ± 0.35 species at JIR, followed by 6.49 ± 0.31 species at WIR and minimum 4.6 ± 0.25

species at TIR. The differences among the reservoirs were highly significant ($p < 0.001$, $F_{(2, 125)}$ 15.57).

Density – Annual mean density of hymenoptera was maximum 200.5 ± 54.37 individuals/m^2 at WIR, 156.2 ± 19.59 individuals/m^2 at JIR and minimum 125.7 ± 16.07 individuals/m^2 at TIR. Non-significant differences ($p > 0.05$, $F_{(2, 125)}$ 1.15) were noted among the three reservoirs.

Shannon Weiner Species Diversity Index (H') – Overall annual mean Shannon Weiner Diversity index for hymenoptera was low. However, annual mean H' was maximum 0.85 ± 0.05 for WIR while for TIR and JIR it was almost same 0.6 ± 0.06. The difference in the mean Shannon Weiner diversity index (H') of the three reservoirs was significant at 0.01 level with $F_{(2, 125)}$ 5.18.

Evenness (E) – Like H', Evenness was also low for hymenoptera and differed significantly with $p < 0.01$ ($F_{(2, 125)}$ 4.82). The evenness was 0.41 ± 0.04, 0.32 ± 0.03 and 0.47 ± 0.02 for TIR, JIR and WIR respectively.

Seasonal Differences in the Species Richness, Density, Shannon Weiner Diversity index (H') and Evenness (E) (Table. 6.5, Fig. 6.6)

Species Richness

Seasonal variations around Each Reservoir

TIR – At TIR mean species richness was maximum 5.17 ± 0.49 species in winter. In summer and Post monsoon it was nearly same with 4.17 ± 0.59 species and 4.18 ± 0.4 species respectively while in monsoon it was 4.9 ± 0.43 species. The seasonal variations showed non-significant differences ($p > 0.05$, $F_{(3,41)}$ 1.09).

JIR – At JIR species richness varied non-significantly across the seasons with maximum mean 7.33 ± 0.83 species noted for summer, 7.25 ± 0.84 species in monsoon, 6.14 ± 0.26 species in post-monsoon and 6.27 ± 0.52 species in winter ($p > 0.05$, $F_{(3,34)}$ 0.77).

WIR– At WIR also the mean species richness of hymenopterans varied non-significantly ($p > 0.05$, $F_{(3,41)}$ 0.79) and was maintained all throughout the year (6.67 ± 0.7, 6.91 ± 0.65 and 6.67 ± 0.43 species for summer, monsoon and winter respectively) except post-monsoon when it was 5.6 ± 0.72.

Differences among the reservoirs

In summer the species richness was highest at JIR followed by WIR and lowest at TIR. The differences among the reservoirs were moderately significant ($p < 0.01$, $F_{(2, 33)}$ 5.49). In next season monsoon again mean species richness was highest at JIR followed by WIR and lowest at TIR with significant differences ($p < 0.05$, $F_{(2, 26)}$ 3.66). In post monsoon the species richness at the three reservoirs differed in small range of 4.18 to 6.14 but was significant ($p < 0.05$) with $F_{(2,25)}$ 4.14. In the last season winter, highest species richness was observed at WIR followed by JIR and lowest at TIR. The differences among the reservoirs were non-significant ($p > 0.05$, $F_{(2,32)}$ 2.59).

Density

Seasonal variations around Each Reservoir

TIR – At TIR the mean seasonal density of Hymenoptera oscillated over the year with 188 ± 37.69 individuals/m^2 in summer to 93.35 ± 8.62 individuals/m^2 in monsoon to 130.7 ± 44 individuals/m^2 in post-monsoon and finally 85.62 ± 14.39 individuals/m^2 in winter with non-significant ($p > 0.05$, $F_{(3,41)}$ 2.41) seasonal variations.

JIR – At JIR, maximum mean density was recorded during winter (217 ± 57.9 individuals/m^2) and minimum in monsoon (95.24 ± 15.34 individuals/m^2). In summer and post-monsoon densities were 133.3 ± 15.31 individuals/m^2 and 169.7 ± 34.07 individuals/m^2 respectively. The seasonal variations were non-significant ($p > 0.05$, $F_{(3,34)}$ 1.91).

WIR – At the third reservoir WIR, the mean seasonal density was highest 391.1 ± 194.5 individuals/m^2 in winter and lowest 102.7 ± 14.16 individuals/m^2 in post-monsoon while during summer and monsoon densities were 156.2 ± 37.85 individuals/m^2 and 129.7 ± 19.5 individuals/m^2 respectively. The seasonal variations were non-significant ($p > 0.05$, $F_{(3, 41)}$ 1.59).

Differences among the reservoirs

Density varied non-significantly in all the seasons. In summer the highest mean density was recorded at TIR while lowest at JIR ($p > 0.05$, $F_{(2,33)}$ 0.73). During monsoon, densities at TIR and JIR were nearly same while it was higher at WIR ($p > 0.05$, $F_{(2,26)}$ 1.82). During next season post-monsoon highest density was recorded at JIR followed by TIR and lowest at WIR ($p > 0.05$, $F_{(2,25)}$ 0.83) while in winter, WIR had highest mean density of hymenopterans and TIR the lowest ($p > 0.05$, $F_{(2,32)}$1.67).

Shannon Weiner Species Diversity Index (H')

Seasonal variations around Each Reservoir

TIR – Mean diversity index was maximum 0.9 ± 0.12 in monsoon which decreased across the seasons to 0.65 ± 0.13 in post-monsoon and was almost same 0.5 ± 0.1 in winter and summer. The differences across the seasons varied non-significantly ($p > 0.05$, $F_{(3,41)}$ 2.05).

JIR – Highest mean H' was recorded in summer (0.74 ± 0.11) gradually decreasing across the seasons with 0.62 ± 0.14, 0.55 ± 0.2 and 0.46 ± 0.08 in monsoon, post-monsoon and winter respectively ($p > 0.05$, $F_{(3,34)}$ 1.04).

WIR – At WIR maximum mean H' 1.06 ± 0.08 was recorded in summer and minimum 0.58 ± 0.13 in post-monsoon, during monsoon and winter H' were 0.83 ± 0.09 and 0.88 ± 0.07 respectively. Compared to other two reservoirs the seasonal variations were significant at $p < 0.01$ ($F_{(3, 41)}$ 4.49).

Differences among the reservoirs

On an average very low mean diversity index were noted for all the seasons at the three reservoirs. However, highest among these was recorded at WIR in summer which was followed by JIR and lowest for TIR with moderately significant differences ($p < 0.01$, $F_{(2,33)}$ 6.63). During monsoon and post-monsoon maximum diversity index were noted for TIR followed by WIR and minimum for JIR but with non-significant differences ($p > 0.05$) in both the seasons with $F_{(2, 26)}$ 1.41 and $F_{(2, 25)}$ 0.1 respectively. While in winter maximum mean H' was noted for WIR followed by TIR and minimum for JIR with moderately significant differences ($p < 0.01$, $F_{(2,32)}$ 6.62).

Evenness (E)

Seasonal variations around Each Reservoir

TIR – The mean evenness for hymenopterans varied significantly ($p < 0.05$, $F_{(3,41)}$ 3.5) across the seasons with maximum evenness 0.64 ± 0.09 in monsoon which decreased in post-monsoon to 0.43 ± 0.07 and to 0.32 ± 0.05 and 0.33 ± 0.09 in winter and summer respectively.

JIR – At JIR, mean evenness was low in all the seasons with minor variations. They were 0.38 ± 0.05, 0.33 ± 0.07, 0.31 ± 0.11 and 0.25 ± 0.04 in summer, monsoon, post-monsoon and winter respectively ($p > 0.05$, $F_{(3,34)}$ 0.83).

WIR – The mean evenness showed moderately significant variations ($p < 0.01$, $F_{(3.41)}$ 5.66) across the seasons with highest evenness 0.59 ± 0.03 recorded in summer and lowest 0.33 ± 0.06 in post-monsoon. It was more or less same in monsoon and winter with 0.45 ± 0.05 and 0.47 ± 0.04 respectively.

Differences among the reservoirs

Highest evenness was noted at WIR in summer, when TIR and JIR both had lower evenness ($p < 0.05$, $F_{(2, 33)}$ 5.0). In monsoon highest mean evenness was recorded for TIR and lowest for JIR with significant ($p < 0.05$, $F_{(2, 26)}$ 4.38) differences. Overall low evenness was found in post-monsoon with non-significant differences ($p > 0.05$, $F_{(2.25)}$ 0.65) while in winter, JIR had minimum evenness followed by TIR and maximum for WIR. The differences were moderately significant ($p < 0.01$, $F_{(2,32)}$ 6.9).

Annual Percentage Occurrence (Table 6.6, Figure 6.7)

When the annual percentage occurrence of the hymenopteran families is considered, family Formicidae was the most common family at all the three reservoirs. Though Sphecidae was recorded at all the three reservoirs its annual percentage occurrence was very low along with Chrysididae which was represented only at WIR.

TIR - At TIR, 79.25 % of the hymenopterans were accounted by family Formicidae followed by Apidae with 12.26%, Xylocopidae with 3.77%, Vespidae with 3.3% and Sphecidae with minimum 1.42%.

JIR - At JIR again Formicidae dominated with 60.96 % of the total hymenopteran population followed by 15.14% of Apidae, 11.55% of Xylocopidae, 9.16% of Vespidae and minimum 3.19% of Specidae.

WIR - At WIR, maximum 67.13 % of the total hymenopterans were represented by family Formicidae and minimum 0.35% each by both families Specidae and Chrysididae. Apidae contributed to 18.18% while Vespidae and Xylocopidae 8.04 % and 5.94% respectively.

Differences among the reservoirs

When the differences among the reservoirs are considered for the annual percentage occurrence it is observed that Formicidae is the most dominant family at all the reservoirs with highest percentage at TIR among the three. Vespidae, Sphecidae and Xylocopidae had higher percentage occurrence at JIR as compared to other two reservoirs while Apidae had the highest percentage occurrence at WIR.

Seasonal Percentage Occurrence (Table 6.7, Figure 6.8)

As was observed in the annual percentage occurrence in the seasonal percentage occurrence too, Formicidae was the most dominant family of the order Hymenoptera in all the seasons at all the reservoirs followed by family Apidae. The dominance of Xylocopidae and Vespidae changed depending on the seasons and the habitats.

Formicidae, Vespidae, Xylocopidae and Apidae were present at all the reservoirs during all the seasons of the year. Specidae was present in all the seasons at JIR, during summer and monsoon at TIR and only in monsoon at WIR while family Chrysididae was absent in all seasons at all reservoirs except its presence in winter at WIR.

Seasonal differences around reservoirs

As for earlier chapters, for Hymenoptera also percentage occurrence of different families in a particular season at each reservoir is taken into consideration.

Summer

TIR –All the five families recorded at TIR were present during summer with highest 75.93% of Formicidae followed by 12.96% of Apidae, 5.56% of Xylocopidae, 3.7% of Specidae and 1.85% of Vespidae.

JIR – At JIR also all the five families recorded in annual study were present in summer with highest 49.38% of Formicidae, while Apidae, Xylocopidae and Vespidae contributed 18.52%, 14.81% and 12.35% respectively and the lowest percentage occurrence was of Sphecidae with 4.94%.

WIR – At WIR, only four families were present in summer with Formicidae dominating with 64.56%. Other families contributing to the percentage occurrence include Apidae with 20.25%, Vespidae with 8.86% and Xylocopidae with 6.33%.

Monsoon

TIR – In monsoon the same percentage occurrence to that in summer was observed for family Formicidae (75.93%). The percentage occurrence of other families was 16.67% for Apidae, 3.7% for Vespidae and 1.85% each for Specidae and Xylocopidae.

JIR – The percentage occurrence of Formicidae increased from summer and it contributed 60% of the total hymenopterans while that for Vespidae was 12.73% nearly same as noted in summer. Decrease was noted in the other groups with 1.82% for Specidae, 9.09% for Xylocopidae and 16.36% for Apidae.

WIR - In monsoon five families were noted at WIR with Formicidae dominating with 65.28% occurrence followed by 15.28% of Apidae, 12.5% of Vespidae and 5.56% of Xylocopidae. Sphecidae was the fifth family that was observed only during monsoon at this reservoir with 1.39% occurrence.

Post-monsoon

TIR – In post-monsoon only four families were present at TIR with 80% contributed by family Formicidae and 12.5% by Apidae while families Vespidae and Xylocopidae contributed 5% and 2.5% of the hymenopteran population respectively.

JIR – At JIR, during post-monsoon the percentage occurrence of family Formicidae was 62.22% while for Apidae it was 15.56%, Xylocopidae 11.11% and Vespidae 8.89% of the total hymenoptera. Sphecidae represented the least 2.22% of hymenopterans.

WIR –Again in post-monsoon only four families were present at WIR with 63.16% of Formicidae, 19.3% of Apidae and 8.77% each of Vespidae and Xylocopidae.

Winter

TIR – In winter again only four families were observed at TIR with maximum 84.36% contributed by Formicidae while 7.81%, 4.69% and 3.13% contributed by Apidae, Xylocopidae and Vespidae respectively.

JIR - All the five families were present with 74.29% contributed by Formicidae while 10% each by Xylocopidae and Apidae and 2.86% each by Vespidae and Sphecidae.

WIR - In winter five families were recorded at WIR with 74.36% of Formicidae, 17.95% of Apidae, 3.85% of Xylocopidae and 2.56% of Vespidae. New family in the list Chrysididae contributed only 1.28% of the total percentage occurrence.

Differences among the habitats

During **Summer** lower percentage occurrence of Formicidae was observed at JIR compared to other two reservoirs while Vespidae had the highest percentage occurrence. Sphecidae was absent at WIR in summer. Xylocopidae had the highest percentage occurrence at JIR while Apidae at WIR. In **monsoon** highest percentage occurrence of Formicidae was recorded at TIR as was observed in the preceding summer while Vespidae had more or less same percentage of occurrence at JIR and WIR. Specidae also had almost same percentage of occurrence while Xylocopidae had the highest percentage at JIR among the three reservoirs. Apidae showed nearly similar percentage occurrence at TIR and JIR. During **post-monsoon** maximum percentage occurrence of Formicidae was observed at TIR when Vespidae had almost same percentage occurrence at JIR and WIR. Xylocopidae as was observed for the previous seasons had highest percentage occurrence at JIR while Apidae was dominant at WIR among the three reservoirs. Family Sphecidae was represented only at JIR. During **winter** family Formicidae was dominant at TIR as compared to other two reservoirs while Vespidae did not show much difference. Xylocopidae, was dominant at JIR and Apidae at WIR while Sphecidae was present only at JIR and Chrysididae at WIR.

When the comparison of the percentage occurrence is made according to the season at single site it shows following results.

TIR – Summer : Formicidae > Apidae > Xylocopidae > Sphecidae > Vespidae
Monsoon: Formicidae > Apidae > Vespidae > Sphecidae = Xylocopidae
Post-monsoon: Formicidae > Apidae > Vespidae > Xylocopidae
Winter: Formicidae > Apidae > Xylocopidae > Vespidae

JIR - Summer : Formicidae > Apidae > Xylocopidae > Vespidae > Sphecidae
Monsoon: Formicidae > Apidae > Vespidae > Xylocopidae > Sphecidae
Post-monsoon: Formicidae > Apidae > Xylocopidae > Vespidae > Sphecidae
Winter: Formicidae > Apidae = Xylocopidae > Sphecidae = Vespidae

WIR - Summer : Formicidae > Apidae > Vespidae > Xylocopidae
Monsoon: Formicidae > Apidae > Vespidae > Xylocopidae > Sphecidae
Post-monsoon: Formicidae > Apidae > Vespidae = Xylocopidae
Winter: Formicidae > Apidae > Xylocopidae > Vespidae > Chrysididae

Table 6.1: Number of species belonging to the six Hymenopteran families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR).

	Formicidae(20)	**Vespidae (7)**	**Sphecidae (4)**	**Chrysididae (1)**	**Xylocopidae (1)**	**Apidae (3)**
TIR	12	3	2	0	1	2
JIR	11	5	3	0	1	3
WIR	14	5	1	1	1	3

Table 6.2: Abundance rating of Hymenopteran species encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Abundant	**Common**	**Frequent**	**Uncommon**	**Rare**
TIR	1	5	0	3	11
JIR	1	4	4	2	12
WIR	3	2	5	2	13

Table 6.3: Annual and Seasonal Jaccard's Similarity Index (J) of Hymenopterans between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Annual		**Summer**		**Monsoon**		**Post-monsoon**		**Winter**	
	TIR	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**	**TIR**	**JIR**
WIR	0.41	0.55	0.39	0.41	0.37	0.67	0.61	0.71	0.45	0.57
JIR	0.54	-	0.36	-	0.44	-	0.64	-	0.52	-

Table 6.4: Annual Mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of the Hymenopterans at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Species Richness (***) $F_{(2,125)}$ 15.57	**Density (ns) $F_{(2,125)}$ 1.15**	**Shannon Weiner index (**) $F_{(2,125)}$ 5.18**	**Evenness (**) $F_{(2,125)}$ 4.82**
TIR	4.6 ± 0.25	125.7 ± 16.07	0.6 ± 0.06	0.41 ± 0.04
JIR	6.79 ± 0.35	156.2 ± 19.59	0.6 ± 0.06	0.32 ± 0.03
WIR	6.49 ± 0.31	200.5 ± 54.37	0.85 ± 0.05	0.47 ± 0.02

Table 6.5: Seasonal variations in the mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of the Hymenopterans at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

			Summer	**Monsoon**	**Post monsoon**	**Winter**
Species Richness		**Among Reservoirs / Within Reservoirs**	**(**) $F_{(2,33)}$ 5.49**	**(*)$F_{(2,26)}$ 3.66**	**(*)$F_{(2,25)}$ 4.14**	**(ns) $F_{(2,32)}$ 2.59**
	TIR	(ns) $F_{(3,41)}$1.09	4.17 ± 0.59	4.9 ± 0.43	4.18 ± 0.4	5.17 ± 0.49
	JIR	(ns) $F_{(3,34)}$ 0.77	7.33 ± 0.83	7.25 ± 0.84	6.14 ± 0.26	6.27 ± 0.52
	WIR	(ns) $F_{(3,41)}$ 0.79	6.67 ± 0.7	6.91 ± 0.65	5.6 ± 0.72	6.67 ± 0.43
Density			**(ns) $F_{(2,33)}$ 0.73**	**(ns) $F_{(2,26)}$ 1.82**	**(ns) $F_{(2,25)}$ 0.83**	**(ns) $F_{(2,32)}$1.67**
	TIR	(ns) $F_{(3,41)}$ 2.41	188 ± 37.69	93.35 ± 8.62	130.7 ± 44	85.62 ± 14.39
	JIR	(ns) $F_{(3,34)}$ 1.91	133.3 ± 15.31	95.24 ± 15.34	169.7 ± 34.07	217 ± 57.9
	WIR	(ns) $F_{(3,41)}$ 1.59	156.2 ± 37.85	129.7 ± 19.5	102.7 ± 14.16	391.1 ± 194.5
Shannon Weiner index (H')			**(**)$F_{(2,33)}$ 6.63**	**(ns) $F_{(2,26)}$ 1.41**	**(ns) $F_{(2,25)}$ 0.1**	**(**)$F_{(2,32)}$ 6.62**
	TIR	(ns) $F_{(3,41)}$ 2.05	0.5 ± 0.1	0.9 ± 0.12	0.65 ± 0.13	0.5 ± 0.1
	JIR	(ns) $F_{(3,34)}$1.04	0.74 ± 0.11	0.62 ± 0.14	0.55 ± 0.2	0.46 ± 0.08
	WIR	(**)$F_{(3,41)}$ 4.49	1.06 ± 0.08	0.83 ± 0.09	0.58 ± 0.13	0.88 ± 0.07
Evenness (E)			**(*)$F_{(2,33)}$ 5**	**(*)$F_{(2,26)}$ 4.38**	**(ns) $F_{(2,25)}$ 0.65**	**(**)$F_{(2,32)}$ 6.9**
	TIR	(*)$F_{(3,41)}$ 3.5	0.33 ± 0.09	0.64 ± 0.09	0.43 ± 0.07	0.32 ± 0.05
	JIR	(ns) $F_{(3,34)}$ 0.83	0.38 ± 0.05	0.33 ± 0.07	0.31 ± 0.11	0.25 ±0.04
	WIR	(**)$F_{(3,41)}$ 5.66	0.59 ± 0.03	0.45 ±0.05	0.33 ± 0.06	0.47 ± 0.04

Table 6.6: Annual Percentage Occurrence of the hymenopteran families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

	Formicidae	**Vespidae**	**Sphecidae**	**Chrysididae**	**Xylocopidae**	**Apidae**
TIR	79.25 %	3.3 %	1.42 %	0 %	3.77 %	12.26 %
JIR	60.96 %	9.16 %	3.19 %	0 %	11.55 %	15.14 %
WIR	67.13 %	8.04 %	0.35 %	0.35 %	5.94 %	18.18 %

Table 6.7: Seasonal Percentage Occurrence of the butterfly families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

Seasons	**Reservoirs**	**Formicidae**	**Vespidae**	**Sphecidae**	**Chrysididae**	**Xylocopidae**	**Apidae**
Summer	**TIR**	75.93 %	1.85 %	3.70 %	0 %	5.56 %	12.96 %
	JIR	49.38 %	12.35 %	4.94 %	0 %	14.81 %	18.52 %
	WIR	64.56 %	8.86 %	0 %	0 %	6.33 %	20.25 %
Monsoon	**TIR**	75.93 %	3.7 %	1.85 %	0 %	1.85 %	16.67 %
	JIR	60 %	12.73 %	1.82 %	0 %	9.09 %	16.36 %
	WIR	65.28 %	12.5 %	1.39%	0 %	5.56 %	15.28 %
Post-monsoon	**TIR**	80 %	5 %	0 %	0 %	2.5 %	12.5 %
	JIR	62.22 %	8.89 %	2.22 %	0 %	11.11 %	15.56 %
	WIR	63.16 %	8.77 %	0%	0 %	8.77 %	19.3 %
Winter	**TIR**	84.36 %	3.13 %	0 %	0 %	4.69 %	7.81 %
	JIR	74.29 %	2.86 %	2.86 %	0 %	10 %	10 %
	WIR	74.36 %	2.56 %	0 %	1.28 %	3.85 %	17.95 %

Table 6.8: Abundance rating of the Hymenopterans observed around three reservoirs

Sr. No.	Common Name	Scientific Name	TIR	JIR	WIR
	Family: Formicidae				
1	Small red ant	*Oecophylla smaragdina*	C	U	F
2	Small black ant	*Monomorium minimum*	C	C	A
3	Large black ant	*Componotus compressus*	A	A	A
4		*Componotus radiatus*			R
5	Carpenter Ant	*Componotus sericeus*	C	F	C
6		*Componotus sp.1*	U	F	F
7		*Camponotus sp. 2*		R	
8		*Camponotus sp.3*	R		
9		*Camponotus sp.4*			R
10	Red imported fire ant	*Solenopsis invicta*	C	F	C
11		*Solenopsis sp.1*	R	R	R
12		*Solenopsis sp.2*			U
13		*Solenopsis sp. 3*		R	
14	Arboreal Bicolored Ant	*Tetraponera rufonigra*	R	C	U
15		*Dorylus labiatus*		R	R
16		*Monomorium sp.*			R
17		*Lasius sp.*			R
18		*Tetramorium sp.*	R		
19		*Anoplolepsis sp.*	R		
20		*Leptogenys sp.*	R		
	Family: Vespidae				
21	Common Wasp	*Ropalidia marginata*	U	F	F
22	Common yellow jacket	*Paravespula vulgaris*		R	R
23	Paper wasp	*Polistes sp.*			R
24		*Dolichovespula sp.*	R	R	
25	Indian Hornet	*Vespa sp.*		R	
26	Potter wasp	*Eumenes sp.*	R	R	R
27		*Mondia quadridens*			R
	Family : Sphecidae				
28	Thread waisted wasp	*Sphex lobatus*	R		
29		*Sphex sp. 1*		R	R
30		*Sphex sp.2*	R	R	
31		*Sphex sp.3*		R	
	Family: Chrysididae				
32	Cuckoo wasp	*Chrysis sp.*			R
	Family: Xylocopidae				
33	Carpenter Bee	*Xylocopa aestuans*	U	C	F
	Family: Apidae				
34	Bumble Bee	*Bombus psthyrus*	C	C	A
35	Honey Bee	*Apis dorsata*	R	U	F
36	Metallic Green Bee	*Agapostemon virescens*		R	R

Figure 6.1: Number of Hymenopteran species belonging to different families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

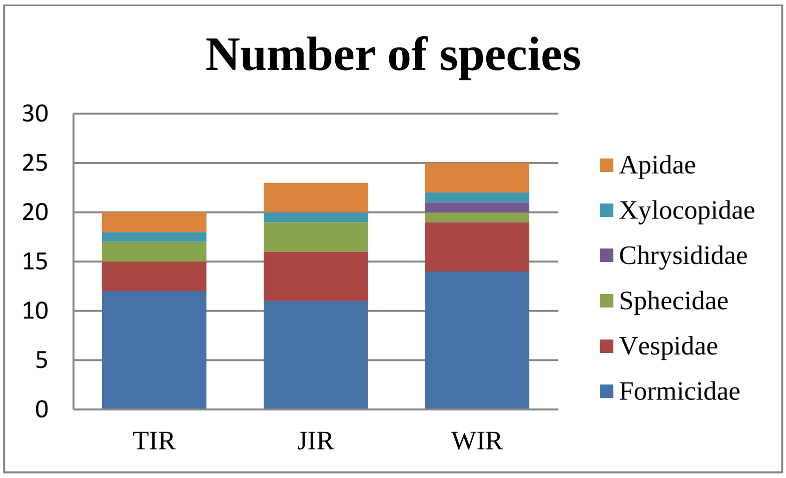


Figure 6.2: Abundance rating of the Hymenopteran species encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

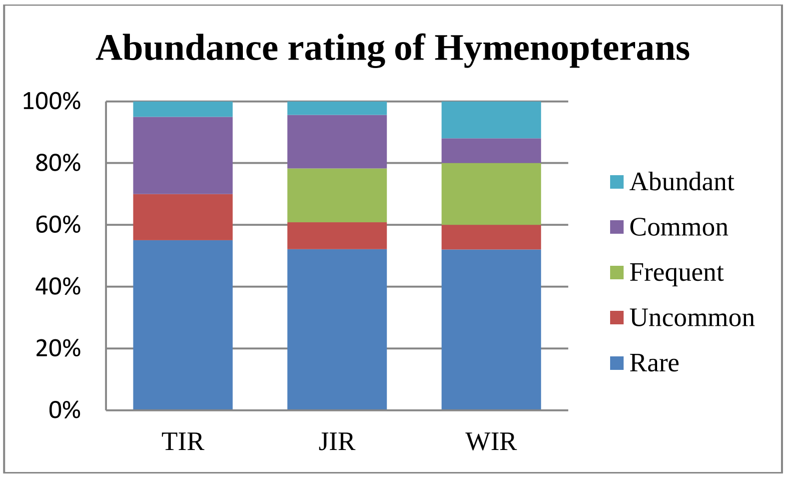


Figure 6.3: Annual Jaccard's similarity Index of Hymenopterans between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

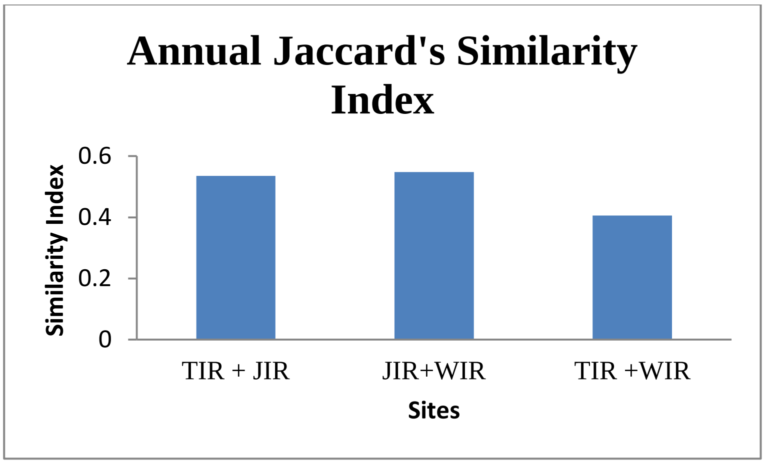


Figure 6.4: Seasonal Jaccard's similarity Index for the Hymenoptera between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

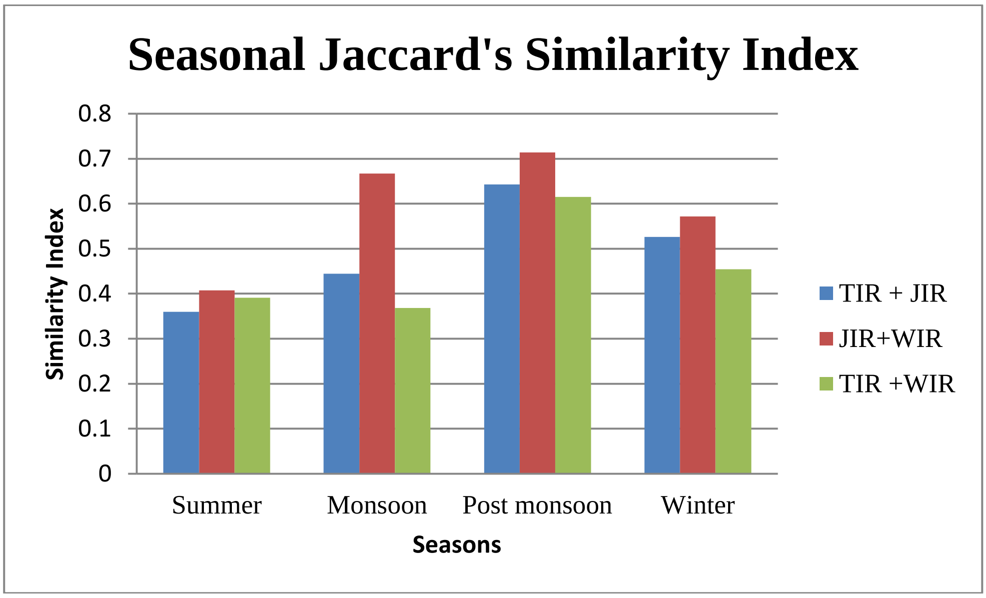
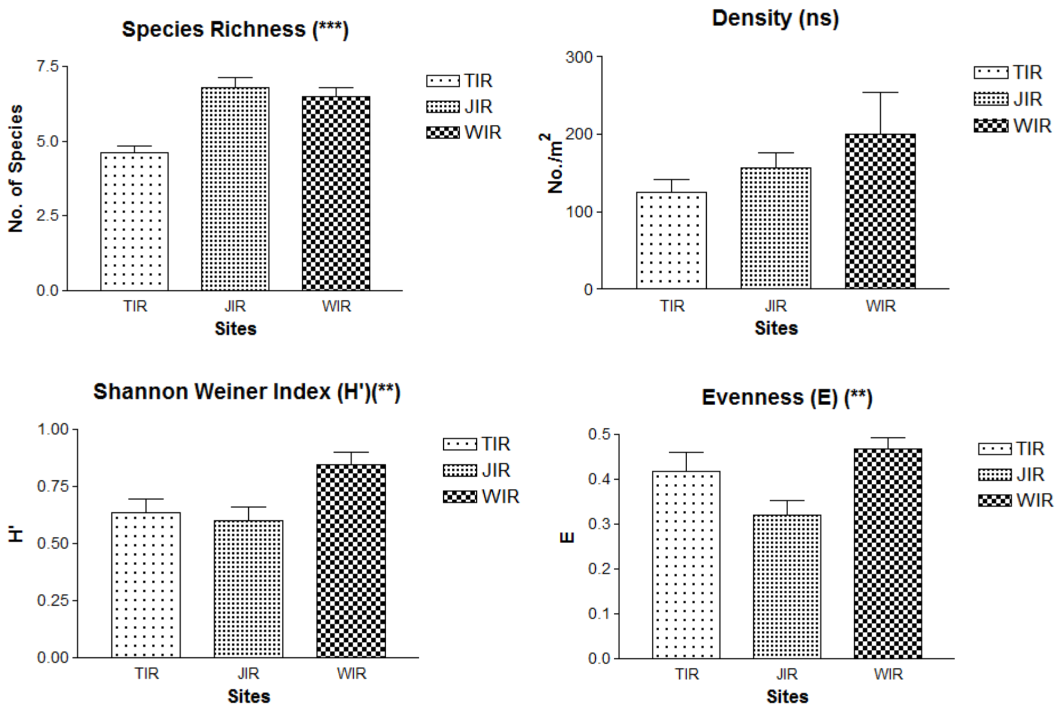
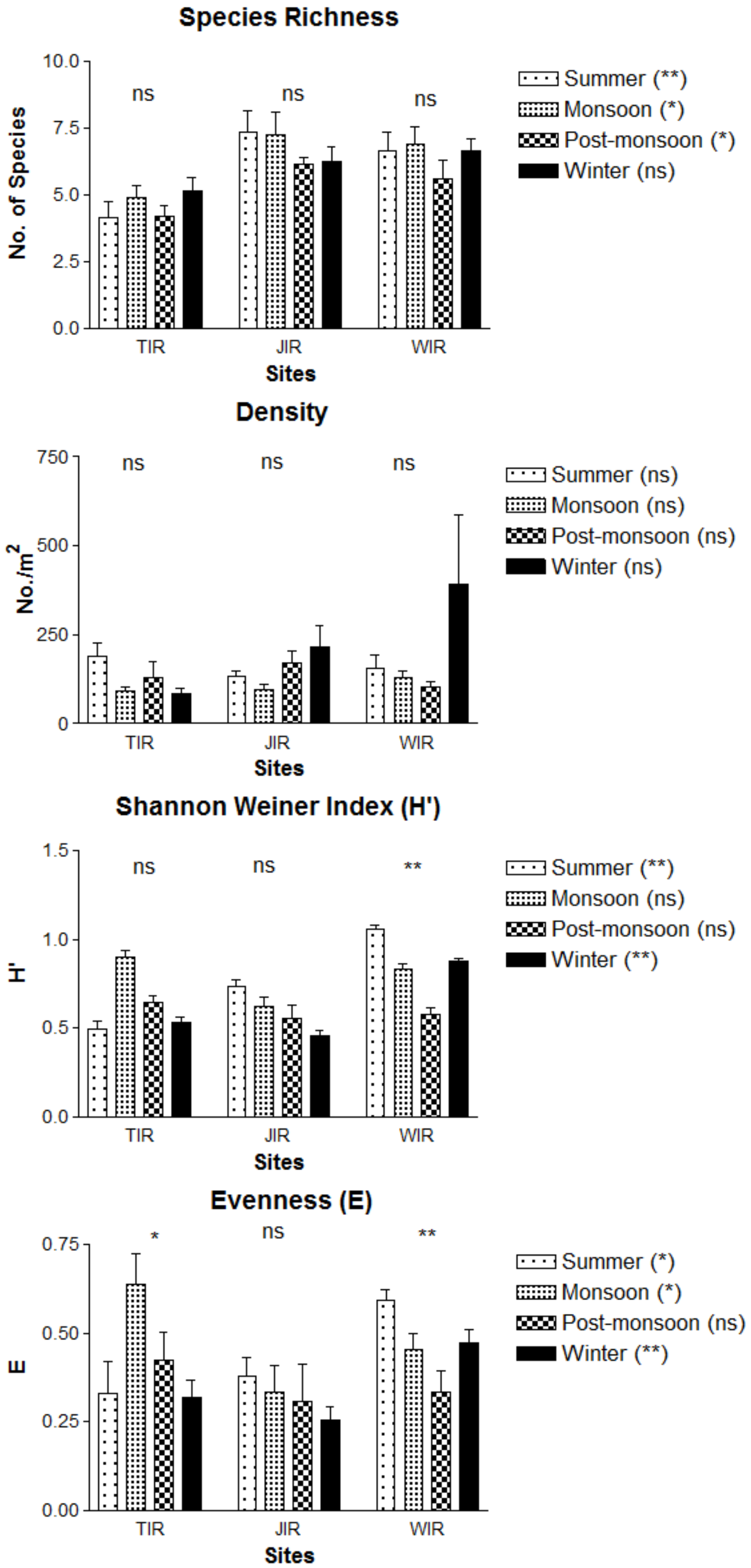


Figure 6.5 : Annual mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of Hymenopterans at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

Figure 6.6 : Seasonal variations in the mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of Hymenopterans at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)



For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *(P < 0.001)**

Figure 6.7: Annual Percentage Occurrence of the six hymenopteran families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

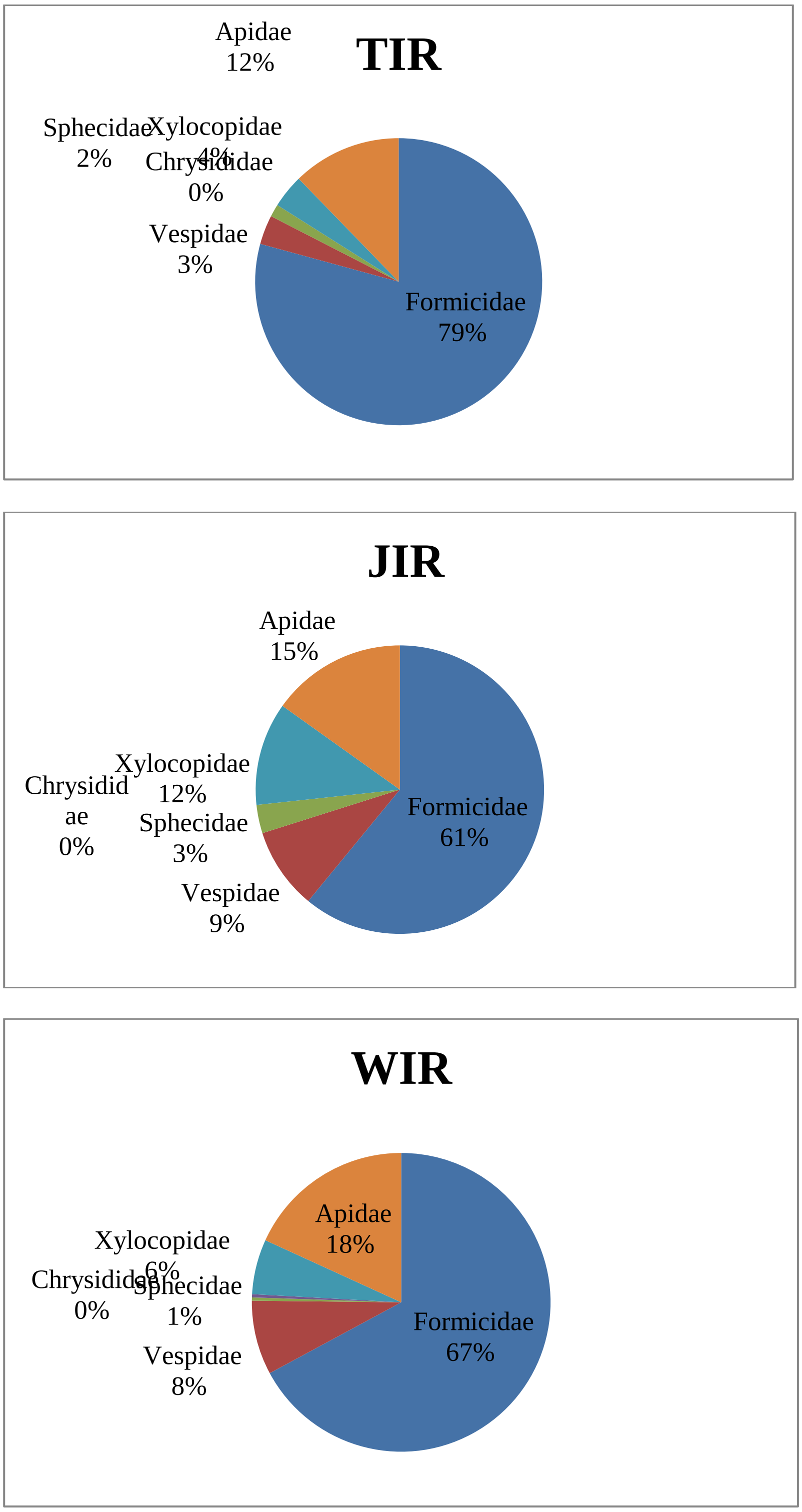


Figure 6.8: Seasonal variations in the Percentage occurrence of six hymenopteran families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

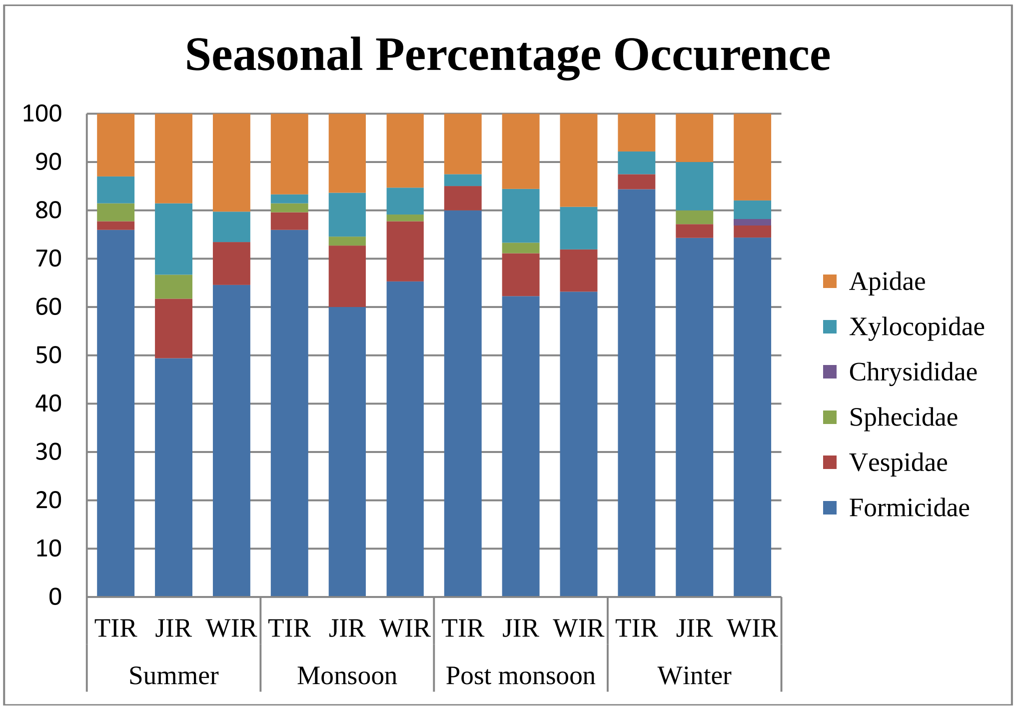


PLATE 11: SOME OF THE COMMON HYMENOPTERANS OBSERVED IN THE STUDY

Camponotus compressus (Large Black Ant)

Solenopsis invicta (Red imported fire ant)

Tetraponera rufonigra (Arboreal bicoloured ant)

Ropalidia marginata (Common wasp)

Xylocopa aestuens (Carpenter Bee)

Apis dorasata (Honey Bee)

Discussion

The ants dominated hymenopteran diversity in the area compared to wasp and bees. The dam being earthen in character and covered with bushes provided good habitat for ants to make burrows under the shade of grasses and bushes. As discussed in earlier chapter bushes are inhabited by treehoppers which produce honey dew attracting ants and form a mutualistic relationship. The ants get food from the honeydew produced from the residual plant sap left by the hemipterans and in turn give protection to treehoppers from the probable predators. A positive correlation between the density of the homoptera and ants has been reported by Sabu *et al.* (2008). The habit of harvesting honeydew from homopterans is widespread across different ant taxa, being more developed in the subfamilies Formicinae, Myrmicinae, and Dolichoderinae (Sudd, 1987; Hölldobler and Wilson, 1990). The formicine genus, *Camponotus*, is by far the best associated ant with the Homopterans (Oliveira and Brandão, 1991; Del- Carlo and Oliveira, 1999). Further, the habitat present around the reservoirs is scrubland and the scrub jungles are favoured by many ant species (Ramesh *et al.*, 2010). Ants are also known as soil engineers (Jones *et al.*, 2004) hence their presence in many habitats is beneficial for the ecosystem as well as organisms in the ecosystem. In all 20 different species of ants were encountered around the three reservoirs. Maximum species were present at WIR the larger reservoir retaining water for longer period and also having larger area with varied micro-habitats compared to TIR and JIR. Agricultural fields present all around WIR and various bushes on the earthen dam housed many different types of ants.

Though comparatively less species of ants were recorded around TIR they amounted to 60% of all the hymenopteran species present with only 40 % species of wasps and bees together. TIR is one of the more disturbed reservoirs separated from agricultural fields on two sides by tar road and scrubs and hence probably less species of wasps and bees.

Ants are known to adapt and survive well in the disturbed and urban habitats (Hölldobler and Wilson, 1990; Kamura *et al.,* 2007; Kumar *et al.*, 2009).

Brian (1978) has reported ants to be found in all types of habitats from Arctic Circle to the Equator. The number of species decline with increasing latitudes, altitude and aridity (Kusnezov, 1957; Fowler and Claver, 1991; Farji- Brener and Ruggiero, 1994; Samson *et al.*, 1997). Maximum ant species have been reported from the tropical areas (Holldobler and Wilson, 1990). The biotic factors known to influence the ant abundance include the prey resource availability and predators (Darlington, 1971; Janzen, 1983; Holldobler and Wilson, 1990; Stork and Brendell, 1990; Olson, 1994; Bruhl *et al.*, 1998; Sabu *et al.*, 2008). The prey resources present in the habitat are also one of the important determinants of the ant density (Sabu *et al.*, 2008). However, soil and vegetation types are primary determinants that have higher effect on the ant community composition rather than the disturbances. The disturbances induce changes in the species composition but do not affect the overall abundance (Hoffmann, 2010). Thus, influence of soil and vegetation on the ant communities is not surprising, given that soil type is a major determinant of vegetation (Daubenmire, 1974; Bestelmeyer *et al.*, 2006) that influences ant community composition (Andersen, 1995).

Oecophylla smaragdina, *Monomorium minimum*, *Componotus compressus*, *Solenopsis invicta and Tetraponera rufonigra* are some of the common ant species found in India (Bharti and Sharma, 2009). *Componotus compressus* was the most abundant hymenopteran present at three study areas. Bharti and Alpert (2007) reported this genus to form the major bulk of fauna at different elevations in the Jammu-Kashmir Himalaya. This most common genus of ants is found in a variety of habitats (Chavhan and Pawar, 2011) that include many terrestrial habitats varying from urban to agriculture (Kumar and Mishra, 2008) as well as on the edges of the wetlands - on ground and in bushes (Personal Observation). *M. minimum* was also one of the common species present at all the three reservoirs. In Gujarat this ant is considered auspicious as its presence is considered to increase the wealth in the house. It is routinely observed in the residential areas with gardens. The other species *S. invicta* was very common ant found in large colonies at all the reservoirs, on the ground as well as on the bushes, in search of honey dew while *Tetraponera rufonigra* was another common species found at JIR mainly on the ground. Though not common it was observed frequently at WIR but was rare at TIR. Other ant species found around the reservoirs were rare. *C. componotus* and *S. invicta* are the two dominant social ants of the present study principally influencing the density of the overall hymenopteran group.

At JIR, bees and wasps together formed more than 50% of the hymenopterans. JIR is less disturbed reservoir with less human interventions and hence was preferred more by the wasps which are known to build their nest in the remote localities with low disturbance (Kumar *et al.*, 2009). Though WIR is also a less disturbed reservoir it is disturbed during weekends especially in winter when many bird watchers visit this Nationally Important Wetland. It had minimum wasp species and those that were present were very rare. As the earthen dam is used by the locals for visiting neighboring villages the sparse vegetation is frequently disturbed preventing the colonization of the wasp species. Looking at the bee diversity, in addition to the three bee species common at all the three reservoirs, one more species *Agapostemon virescens* was recorded at two undisturbed reservoirs JIR and WIR. As bees are pollen or nectar feeders they were present around the three reservoirs surveyed where small bushes could offer them food.

Among the different species of wasps encountered in the present study, *Ropalidia marginata* belonging to family Vespidae was the most frequent species while rest were observed only once or twice. *R. marginata* known to be one of the most common social wasp species of peninsular India (Van der Vecht, 1962) was also a common species in the present study. However, other wasps were rare in their appearance and hence overall wasp diversity was low. Among the three reservoirs, minimum species of wasps were recorded from TIR while maximum from JIR.

Seasonality is known to affect the species richness and abundance of the wasp species (Kumar *et al.*, 2009). In addition, precipitation has also been reported to affect the abundance of certain species of paper wasps (O'Donnell and Joyce, 2001). In the present study too, the seasonal patterns may have occurred in the species richness but as their density was too low the effect was not significant. Abundance of the preferred prey items increases the abundance of the wasps. Paper wasps are known to collect herbivorous insects, especially caterpillars to feed their larvae (Rabb, 1960). Wasps of sub family Polistinae (*Polistes sp.*) are mainly carnivorous feeding on arthropod preys, primarily insects of various orders but with a great preference for lepidopteran caterpillars. The diets of several larval and adult wasps include nectar and other vegetal juices. Most species construct aerial nests at height from the ground varying with species preferences and nest site availability (Silveira *et al.*, 2008), the habitats less available around the reservoirs in the semi-arid zone of Central Gujarat.

Among the bees, Honey Bees (*Apis dorsata*) were most common species observed at WIR where honey combs are present near the interpretation center. At TIR honey bees were observed only twice during summer 2009 hence considered as a rare species, while for JIR honeycomb was observed in the Jawla Village about 700 m away from the reservoir and hence the frequency of the honey bee sightings during their exploratory visits was high but in low numbers. Geographical features, altitude of place, morphological characters *etc.* determine the distribution of honey bees (Shruthi *et al.*, 2009) with weather being of prime determinant of bee activities (Traynor, 1966). Thus, bees are observed in specific set of climatic conditions. The presence of honey bees in any area also depends greatly on the flowering season. In a study of Nilgiri Biosphere Reserve, *A. dorsata* colonies were more prominent during January to June (Roy *et al.*, 2011). This season has been reported to be the flowering season in the area (Murali and Sukumar, 1994). In the present study, on an average most of the honey bee encounters occurred during early summer at the three reservoirs. During other parts of the year though honey bees were encountered at JIR and WIR their numbers were too small compared to summer, especially around WIR, where they were observed collecting or feeding on nectar from the small plants growing on the edge of the reservoir.

Bumble bees (*Bombus psythrus*) were found all round the year at the three reservoirs. They were also seen feeding on the small flowers of the bushes on the earthen dam at JIR and WIR but less frequently at TIR. No specific seasonal preference was observed for *B. psythrus.*

Carpenter Bee (*Xylocopa aestuans*) was the most common bee at JIR while at other two reservoirs it was less frequent. The influence of urbanization at TIR probably affected the food resources of these bees and hence all the three bees were spotted less frequently here. Carpenter Bees were encountered maximum at JIR as the vegetation on the earthen dam is not cleared like other two reservoirs and hence more food resources are available. With the decrease in the availability of resources, organisms shift to the habitats which have more resources - a very common phenomenon (Guinther, 2012). This was found to be true at WIR where as the available resources were utilized, the honey bees and solitary bees probably shifted to the other neighbouring environment where more resources were available with low competition. Another specialty of these species is that spring and summer are their most preferred seasons (Hu, 2006).

Abundance Rating

In any habitat, the number of abundant species is always low and that of the rare high (Shelton and Edward, 1983; Krebs, 1985; Kandibane *et al.*, 2005). For Hymenopterans in the present study also, the number of abundant species was very low and that of rare species high. The rating of the species greatly depends on the habitat in which they inhabit. Rating of only one species of ant *C. compressus* as abundant at all the three reservoirs, could be attributed to its uniform presence in varied habitats. *Camponotus* is a worldwide, dominant ant genus that usually occurs with high local abundance and large numbers of species in most zoogeographical regions (Wilson, 1976; Hölldobler and Wilson, 1990). As said earlier *Camponotus sp.* is known to be best associated with the Treehoppers and hence as the population of Treehopper increases so does that of *Camponotus* (Del-Claro and Oliveira, 1999). Small Black ant - *M. minimum* rated abundant at WIR while common at TIR and JIR and Red Imported Fire Ant - *S. invicta* and Carpenter ant - *C. sericeus* rated as common at TIR and WIR are also quiet common species in the area. The difference in their rating may be due to the differences in the microhabitats at the specific reservoirs in this semi-arid zone. Although *S. invicta* is one of the dominant species in terms of density it was rated common, as it was encountered less in the earlier part of the study *i.e.* summer and monsoon of the first year. *C. sericeus* is the species that was found in small groups or in pairs. Although common it had low density as it is known to forage solitarily near to the agricultural fields (Kumar and Mishra, 2008). Arboreal bicoloured ant - *T. rufonigra* was not so common species at TIR, but was common at JIR. However, ecology of this ant species is not known and needs to be studied. The other species of ant; Small Red Ant - *O. smaragdina* rated as common species at TIR is known to occur in large groups preying on large insect species (Kumar and Mishra, 2008). Except 5 common species of ants (*Oecophylla smaragdina, Monomorium minimum, Componotus compressus, Solenopsis invicta and Camponotus serius*), all the other encountered ant species were rare. The studies by Da Silva and Silvestre (2004), Silva *et al.,* (2007) and Delabie *et al.,* (2000) have shown high incidences of rare species in the ant communities.

Bumble bee - *B. psythrus* rated abundant at WIR while common at TIR and JIR are more frequent during early flowering season (Deka *et al.*,2011). They are active in cold climate as their long hair coat helps them to stay warm (Williams, 1998; Cameron *et al.*, 2007; Williams *et al.*, 2008). Hence, in the present study these were found all round the year without any specific seasonal preference and rated as either abundant or common species. Since, bumblebee communities are easy to sample because of their close dependence on habitat characteristics, they are suggested to be good biological indicators for assessing the health of the environment, especially agricultural one (Kevan, 1999; Sepp *et al.*, 2004; Xie *et al.*, 2008). In addition, Carpenter bee *Xylocopa aestuans* a common, frequent and uncommon species of the three reservoirs is known to visit a large variety of plants and play an important role in large scale pollination (Lane, 1999; Moncks, 2001; Cervancia, 2003; Raju and Rao, 2006) hence it was common in the area with agricultural fields. It is also attracted to the plants like *Acacia*, *Calotropis* and *Prosopis* which are common in the semi arid zone. In the absence of this bee the plant species adapted to pollination by this bees do not fruit (Raju and Rao, 2006).

A. dorsata, an important species of honey bee for the pollination of the plants as well as for its unique ability to produce honey, was rated as Frequent at WIR. One of the reasons for only frequent appearance of *A. dorsata* may be its migrating ability in response to the varying floral resources (Dyer and Seely, 1994). Important characteristics of this species are ability to expand rapidly in the presence of abundant floral resources (Itioka *et al.*, 2001) and wide food preferences suggesting low level of floral specialization (Roy *et al.*, 2011). As *A. dorsata* is a species requiring presence of tall trees and cliffs for nesting (Seeley *et al.*, 1982; Thomas *et al.*, 2009), availability of such site is the major limiting factor in the distribution and abundance of the species (Roy *et al.*, 2011).

Ropalidia marginata the only wasp species rated as frequent is the most common wasp species found in India and countries like Pakistan, Sri Lanka of South-east Asia and Australia (Van der Vecht, 1941; 1962; Das and Gupta, 1983). This species of wasp is a social wasp preferring to build its nest in closed spaces with small openings, like bushes and various manmade structures like electric poles, pillars, crevices of buildings, *etc.* as well as at the bottom of the park benches. At the three reservoirs many bushes along with the earthen dam can provide crevices that may facilitate the colonization of these social insects. Another reason for frequent appearance of this species may be due to its seasonal, indeterminate and perennial colony cycle, which means that nest initiation occurs round the year, and nests are active throughout the year (Gadagkar *et al.*, 1982; Chandrashekara *et al.*, 1990; Shakarad and Gadagkar, 1995).

Jaccard's similarity Index

When annual Jaccard's similarity index is considered for hymenopterans, overall low similarity was observed among the three reservoirs. These differences could be due to four reasons. First the difference in the size of the reservoir as has been reported by Guinther, (2012) as area-species richness hypothesis. Secondly the differences caused by Narmada inundation leading to disparity in soil-moisture content and vegetation structure. Third, due to differences in clearing of vegetation, for maintenance of the earthen dam, that destroys the habitat for ground as well as arboreal hymenopterans and lastly the urban influence that all together produces different microhabitats at the three reservoirs leading to the habitats being inhabited by different species and hence low similarity.

However, when the seasonal similarity index is considered, similar trend was noted during summer and winter when the similarity indices were low. Nevertheless the similarity index between JIR and WIR during monsoon and between all the three reservoirs in post-monsoon indicate a short favourable period when macroclimatic conditions are favourable in the semi arid zone of Central Gujarat. This is the period of high productivity and resource availability due to moderate rains leading to distribution of hymenopterans in wider areas resulting in higher similarity index.

Annual Differences in Mean Species Richness, Density, Shannon Weiner Diversity index (H') and Evenness (E)

Minimum annual species richness at TIR clearly indicates the effect of human disturbances on the habitat reducing the number of hymenopteran species supported. Very little differences are noted in the annual species richness of the comparatively undisturbed reservoir *i.e.* JIR and WIR suggesting that the habitat with undisturbed agricultural matrix support more hymenopterans species compared to those that are under urban influence. Ant species richness generally increases with increase in vegetation and declines with increase in disturbance (Kumar *et al.*, 1997).

The annual density was in accordance to the size of the reservoir, largest reservoir having highest density while smallest with the lowest density. However, overall density was high at all the reservoirs as the main species contributing to high annual density was *C. compressus* whose colonies were present on the ground as well as the bushes of the earthen dam of all the three reservoirs all round the year. This resulted in low Shannon Weiner diversity index (0.6 - 0.85). However, this low annual diversity index was maximum at WIR due to presence of comparatively more species which could colonize the undisturbed habitat. The low annual H' also resulted in low Evenness at all the reservoirs indicating mono-dominance of *C. compressus*. However, this dominance was shared with different species *i.e. Solenopsis invicta* and *Apis dorsata* in different seasons at WIR. At TIR and JIR, also *C. compressus* was the dominant species contributing to the higher density and lower H' and Evenness.

Seasonal Differences in Mean Species Richness, Density, Shannon Weiner Diversity index (H') and Evenness (E)

Species Richness

As species are the fundamental components of Biodiversity, there has been long interest in the number of species inhabiting any community (Bisby, 1995; Gaston, 1996). Hence species richness is estimated at all the instances even when other parameters are not considered. This is the most important parameter considered in any biodiversity study as whenever any habitat is discussed, the principal component is the number of species that it supports. However, the observed number of species is always a bias estimate of the community as the actual richness is always higher than the observed (Longino *et al.*, 2002).

In contrast to other insect groups, highest hymenopteran species richness was observed in different seasons at the three reservoirs with maximum species richness during winter at TIR. Cold climatic conditions restrict the movement of majority of insects. But for the hymenopteran that includes ants, wasps and bees that nest mostly in the ground and wood boring species in the bushes, the diverse vegetation composition and soil stability has been reported to increase the species richness in winter (Vanquez *et al.*, 2008). During other seasons, summer which is the favourable season for the Odonate species (Chapter 3) and post monsoon which is considered as favourable season for the butterflies (Kunte, 1997, Chapter 5), the species richness of Hymenopterans was low.

Contrary to this, JIR had higher hymenopteran species richness during summer and monsoon due to the presence of honey bees and metallic green bees with many species of wasps. Hymenopteran species richness in post-monsoon and winter were also good here due to the presence of some of the rare ant species along with the solitary bees that were not observed at other two reservoirs.

Except post-monsoon, Species richness at WIR was higher and same in all seasons due to the presence of all the common species (*S. invicta*, *C. compressus*, *C. serius*, *O. smaragdina, M. minimum, B. psythrus, X. aesteuens and Ropalidia marginata)*. In addition the presence of Honey bees aided in the mean species richness during summer and winter while some of the rare ant species along with the wasps increased the mean species richness in monsoon. Lower species richness recorded in post-monsoon can be attributed to the absence of the rare species of ants along with the wasp species.

The maximum mean species richness at JIR among the three reservoirs in all seasons may be indirectly related to the encounter with the above mentioned species during each visit. This influenced the overall species richness.

A peak in the Hymenopteran species diversity at the end of summer and decrease during winter months was observed by Dunn *et al.* (2007). Similar trend was observed at JIR and WIR in the present study. An argument that ants being thermophilic, higher temperature allows more ants to be active (Dunn *et al.*, 2007) stands true in the present study when the species richness was high during the period with higher temperature *i.e.* summer and early monsoon.

Density

Compared to other groups of insects, hymenopteran density was higher due to presence of social insects like ants and bees that contributed to the majority of density, while solitary species contributed mainly to species richness and minimally to overall density. The density varied in different seasons at the three reservoirs. For the hymenopterans nesting on ground, the soil compactness is an important factor (Vanquez *et al.*, 2008). Many species recorded in present study at TIR nest on ground. Summer is considered to be favourable season for most of these hymenopterans as the dry habitat encourages the nest building (Vanquez *et al.*, 2008). Though TIR had high presence of ants all throughout the year, honey bees which are also one of the main density contributing species in summer were absent at this reservoir. Here, lowest density in winter was mainly due to lower density encountered in the year 2010-11 winter when the bushes (the habitat of the main density contributing species *C. compressus)* were cleared for the development of a tar road besides the earthen dam. The lower density of hymenopterans in monsoon can be attributed to the highest moisture content in the soil destroying the habitat of the dominant ant groups. Post monsoon had moderate density when the environmental conditions for both the ground as well as bush dwelling hymenopterans start improving. As reported by Sabu *et al.* (2008) in the Wayanand region of the Western Ghats ant species like *Taponima sp.* and *Myrmicaria brunnea* often depended on the Homopterans for honey dew and hence the population of both were interdependent. In the present study too density of both the groups hompotera and ants were found to be interdependent as is discussed in chapter 4.

Although winter is considered to be unfavourable season due to low temperatures for many insects, higher density of hymenopterans was observed at JIR and WIR in this season. Hymenopteran density depends upon the plant composition and the vegetation cover (Vanquez *et al.*, 2008) which is still dense during winter with compact or tightened soil. This helps in nest building leading to higher density in winter at the two undisturbed reservoirs. The higher density at JIR can be attributed to the *S. invicta* during winter 2009-10 while that at WIR because of the density of the former with *C. compressus*.

At JIR *C. compressus* and *S. invicta* the two dominant ant species contributed to summer density while at WIR it was due to the presence of the ants along with the honey bees. In monsoon frequent rains bathe the bushes resulting in low ant density. In the following season, post-monsoon, comparatively higher density of hymenopterans at JIR can be accredited to the lush green bushes which housed *C. compressus* and *S. invicta*. However, at other undisturbed reservoir WIR, the density during post-monsoon was lowest as all the hymenopterans except *C. compressus* were either not observed or rarely seen.

The seasonal differences among three reservoirs produced different species composition in different seasons. Density was maximum at TIR in summer due to the widespread occurrence of the dominant ant species compared to other two reservoirs. The influence of urban pressures and expansion cannot be ignored where ant density is known to be high (Hölldobler and Wilson, 1990; Kamura *et al.*, 2007). In monsoon it was WIR where density was highest. The earthen dam of WIR is more than 100 years old and has probably stiffened extensively. Different species of ants have been probably nesting on it over decades. This dam probably resists the heavy rains and maintains the stiffness in which ants could build the nest comfortably in comparison to TIR and JIR which probably have softer soil which becomes moist due to rains making the nest building difficult. In post- monsoon the highest density of hymenopterans was observed at JIR due to presence of bushes on the dam itself which housed the dominant ant colonies. The highest density of hymenopterans recorded at WIR in winter - most unfavourable season for the survival of insects, may be correlated to higher population of the Treehoppers and Aphids (Chapter 4) on the bushes as when they feed a sugary secretion is left behind that attracts various species of ants.

Many studies have been conducted on the seasonal activity patterns of ants (Schumacher and Whitford, 1976; Lynch *et al.*, 1980; Whitford *et al.*, 1981; Fellers, 1989; Suarez *et al.*, 1998; Albrecht and Gotelli, 2001; Sanders *et al.*, 2001) that are typically attributed to either species specific environmental preferences for specific windows of temperature (Lynch *et al.*, 1980; Albrecht and Gotelli, 2001), humidity (Levings, 1981; Kaspari, 1993; Kaspari and Weiser, 2000), available resources (Bernstein, 1979), or to competition (Davidson, 1977; Human and Gordon, 1996). But in the present study no such specific seasonal differences in factors were taken into account and the density and diversity of the family Formicidae probably showed variations according to the availability of resources like food and the suitable climatic determinants like temperature. Gotelli and Ellison (2002) suggested that species energy relationships are strongly associated with latitude, elevation, light availability, and vegetation composition at regional spatial scales.

Shannon Weiner Species Diversity Index (H')

Shannon Weiner diversity index (H') simply gives the information about the distribution of the species in space, treating species as symbols and their relative population sizes as the probability. H' was found to be very low. However, the values of H' varied in different seasons at different reservoirs. Very Low H' for hymenopterans over the year at all the three reservoirs indicates lower number of species as compared to the other taxa studied. However, differences over the seasons and among the reservoirs can be attributed to the local climatic conditions like moisture level in soil, bushes on the earthen dams as well as human activities.

In summer and winter the presence of high number of individuals of few species led to the low H' at TIR. Higher H' in monsoon indicates the better distribution of the species in the area. In post-monsoon too the diversity index was low suggesting the poor distribution of the species present.

JIR had overall lowest H' compared to other reservoirs. The H' decreased from summer to winter with maximum in summer and minimum in winter. Lowest H' was observed in winter when all the species observed had great variations in the number of individual while highest H' in summer when maximum species were present. More the uniformity in the number of individuals present of each species higher is the H'.

Overall high H' was observed at WIR compared to other two reservoirs which was lowest in post-monsoon. Opposing conditions were noted in summer when H' was highest but with low number of species that were more uniformly distributed.

The lower values of H' indicate the instability of the hymenopteran communities in the area. The diversity index is greatly dependent on the number of species as well as the number of individuals of certain species.

Evenness (E)

Evenness is the measure of uniformity of a community. The dominance of ant species *C. compressus* and *S. invicta* is reflected as overall low evenness found in all seasons at all three reservoirs. The higher density of these species decreased the Evenness in all the seasons.

Low species richness increases the evenness as variations are less possible. The low evenness in summer and winter at TIR while highest in monsoon can be attributed to the difference in the population of certain species of hymenopterans. Though the number of species is low many of them are social insects establishing huge colonies. This leads to greater variations in the number of individuals of each species decreasing Evenness. The number of individuals varied especially in summer and winter with higher numbers which led to the lower Evenness. At JIR, the dominant ant species had very high population which ultimately reduced the evenness all through the year making the community irregular. Though low evenness was noted for WIR over the seasons it was maximum during summer when few species were more evenly distributed in number. Monsoon and winter had nearly same evenness while lowest evenness was observed in post-monsoon when dominant ant species took over the other hymenopterans. The uniform distribution of the species indicates the stability of the community and *vice-a-versa*. No major differences observed among the reservoirs in the semi-arid zone indicate that conditions for hymenoptera at macro climatic levels remain same.

Annual Percentage Occurrence

As discussed for other parameters, the annual as well as Seasonal percentage occurrence also ranks Formicidae as the most dominant family among all the hymenopteran families because of more than 60% population contributed by ants at the three reservoirs. Formicids are basically the social forms found in huge colonies in varied habitats. Ants occupy different trophic levels (leaf-cutter and harvester ants -primary consumer, predatory ants - secondary consumers/ decomposers) hence their occurrence is usually very high especially in the semi arid zone.

Apidae was the second dominant family in percentage occurrence whose members wander in wide variety of habitats for foraging. Hence, although they are social, their percentage occurrence was lower compared to Formicidae due to their variable existence. The next families with higher percentage occurrence in the area were Xylocopidae and Vespidae which include carpenter bees and wasps respectively. Their occurrence though lower compared to earlier two families, was higher at JIR. These bees and wasp prefer undisturbed habitats with good vegetation cover which was probably available at JIR. As the habitat has not undergone any kind of modification, it still supports the original native fauna of hymenoptera. However, this explanation cannot be applied for WIR where probably inundation has modified the flora present decreasing the occurrence of these two families compared to JIR. Similarly at TIR the expanding urban development with Narmada inundation have also modified the habitat rendering the conditions unsuitable for the survival of these families. Hence the differences observed in the percentage occurrence at the three reservoirs were the result of the influences caused by the microhabitat at the regional level.

At WIR Vespidae had higher contribution than Xylocopidae due to the presence of *R. marginata.* Specidae the family of solitary wasps although was present at all the three reservoirs had low percentage occurrence principally due to their solitary nature which reduces the encounter of more number of species.

Among the three reservoirs Formicidae had higher abundance at TIR. Most of the species belonging to other families of Order Hymenoptera were rarely observed. These species do visit TIR but may not be able to establish themselves in the disturbed habitat. The rare species may have been encountered during their exploratory visits. JIR had comparatively lower percentage occurrence of Formicidae as other families also contributed to the percentage occurrence. WIR had higher occurrence of Apidae due to the higher frequency of honey bees compared to other reservoirs.

This indicates that among the three reservoir JIR is the least disturbed habitat where other families are though not contributing extensively, do contribute well in the percentage occurrence whereas at WIR some habitat modification and at TIR extensive habitat modification have favoured specific groups of hymenopterans to establish themselves while others are moving away. Human modified habitats are preferred by certain species only and hence other organisms preferring the natural habitat move away in the search of appropriate environmental conditions.

Seasonal Percentage Occurrence

The seasonal percentage occurrence showed the same trend as that of annual with maximum % occurrence of family Formicidae. At TIR more than 75% of the population was composed of ants in all the seasons while Apidae was the second dominant family. As said earlier, nearly 60% of the species composition was attributed to Formicidae at TIR hence the higher % occurrence of the family. The presence of Apidae varied in different seasons of the year with maximum percentage occurrence in monsoon due to presence of bumblebee *B. psythrus* the nectarivore species. This species prefers monsoon when the vegetation flourishes providing more food resources. Xylocopidae had highest occurrence in summer as Carpenter Bee *X. aestuens* was more frequent in this season. Hu (2006) has also reported the period of spring to early summer to be the favourable season for this species and hence they had higher percentage occurrence. At TIR Sphecidae had low % occurrence as the wasp species were rarely seen. This family was totally absent during post-monsoon and winter indicating that habitat available at TIR is not preferred by this family. Similarly Vespidae which includes the most common of all wasps, *R. marginata*, also do not prefer this habitat and had low percentage occurrence as it was observed only on few occasions.

At JIR where other hymenopteran families are comparatively well represented, seasonal percentage occurrence of Formicidae varied between 49% in summer to 74% in winter. At this undisturbed habitat burrowing formicids were probably not much affected in winter. Bees were also more prevalent in comparison to the Wasp families as the latter could not sustain cold. However, in summer, due to the presence of the Honey bees the percentage occurrence of the Apidae increased. Increase in the percentage occurrence of this family lead to decrease in percentage occurrence of Formicidae. During rest of the year the percentage occurrence of Apidae was mainly contributed by Bumble bees. Xylocopidae though had a single species it was a regular species contributing the comparable percentage occurrence in all seasons. Of the wasp families, Vespidae had good representation in all seasons mainly due to the presence of *R. marginata.* In winter when this species was less frequent the % occurrence of this family decreased. Although having low occurrence Specidae was present all throughout the year at JIR. The species of this family were observed only once or twice in the whole season.

At WIR also the dominance of family Formicidae is indisputable due to its higher species richness and 100 % occurrence of the common ant species like *M. minimum, C. compressus, C. serius* and *S. invicta.* The presence of Bumble bees all throughout the year and the honey bees in late winter as well as whole of the summer made Apidae the second dominant family at WIR. The availability of the pollen and nectar greatly determines presence of honey bees. During rainy season as the pollen availability decreased the bee flora was low (Shruthi *et al.*, 2009). *Xylocopa* of family Xylocopidae that depends upon the flowering plants occurred all throughout the year with low % occurrence as the availability of flowering plants varied. Occurrence of family Vespidae was mainly due to the same common wasp species *R. marginata*. Its reduced mobility results in its adaptation to the local climatic regime (Wenzel, 1998; Hozumi *et al.*, 2005). At WIR the presence of two wasp families Sphecidae and Chrysididae only during monsoon and winter respectively indicates that the favourable conditions for them to forage are not available around the reservoir leading to their lowest percentage occurrence.

Effects of different Anthropogenic pressures on the Biodiversity

Livestock grazing is one of the main activities which have positive as well as negative effects on the biodiversity. Most of the Livestock species are exotic to the ecosystem in which they graze, and thus can be seen as a widespread human-caused, chronic disturbance (Vanquez *et al.*, 2008). Browsing and trampling by Livestock can change the vegetation pattern which could ultimately lead to the modification of the habitat and affect the biodiversity present in the area. Live stock grazing is observed around all the three reservoirs, but only during certain period of the year. The low levels of grazing observed, is not thought to modify the habitat and affect the diversity and density of ants. Most of the studies showing the effect of livestock grazing on the ant community composition reported higher abundance (Andersen and Mckaige, 1987; Putman *et al.*, 1989; Scougall *et al.*, 1993; Bromham *et al.*, 1999; Read and Andersen, 2000) and lower species richness (Andersen and Mckaige, 1987; Abensperg-Traun *et al.*, 1996; Nash *et al.*, 2001; Woinarski *et al.*, 2002) of ants in the grazed grounds compared to the non grazed. Hence grazing can pose indirect effects on the ant community composition by changing the vegetation patterns, food supplies and competitive interactions (Andersen, 1995). At the three reservoirs studied, the ants contributed principally to the density and diversity of hymenopterans.

Agricultural practices such as heavy grazing, irrigation, drainage, fertilizers, mowing, conventional tillage, ploughing, and reseeding have been reported to reduce ant biodiversity and/or biomass, and colony densities (Kanowski, 1956; Breymeier, 1971; Galle, 1972; Willard, 1973; Pisarski, 1978; Diaz, 1991; Perfecto and Snelling, 1995; Radford *et al.*, 1995). However, other studies have reported ants to tolerate, recover and re-invade the same habitat after such disturbances (Petal, 1976; Andersen, 1991; Lobery de Bruyn, 1993; Folgarait *et al.*, 1997). It has also been reported that despite the reduction in ant species richness, the overall abundance of ants increases due to the dominance of aggressive species (Folgarait, 1998). However, a large number of ant diversity and density occurs at the edges of the agricultural fields (Kumar and Mishra, 2008). In the present study, presence of agricultural fields around the reservoir may have shifted the ants towards the reservoir due to the disturbances caused by agricultural practices.

Pollution – Ants are known to exhibit higher tolerance to pollution especially radioactive (Torossian and Causse, 1968; Le Masne and Bonavita-Coug-urdan, 1972) and industrial (Petal *et al.*, 1975) compared to other invertebrates. This can be attributed to the fact that very low population of ants is outside the nest and they change their activity pattern depending on the time of exposure to the pollutants (Folgarait, 1998). However, the density and size of ant colonies decreases with the increase in pollution (Petal, 1978a). The human intervention produces pollution at TIR in the form of domestic waste but no industrial or radioactive pollution is present around any of the reservoirs hence probably no effect of pollution on the ant species richness and density in the area.

Forest fire is also one of the major causes for destroying the fauna of the area. Significant decrease in the ant fauna has been observed after slashing and burning of a tropical forest in Mexico (Mackay *et al.*, 1991). However, at TIR too, during late winter or early summer the bushes on the dam are burnt off annually to maintain the rigidity of the earthen dam. The vegetation burnt is scrub vegetation which burns fast in short period probably without heating the ground much hence no significant changes were found in the ant diversity as majority of the ants nest underground. Nevertheless, the fires led to complete loss of the habitat for treehoppers inhabiting the bushes and also some of the arboreal ant species.

Advantages of the Hymenoptera in ecosystem management

- The construction of ant nests changes the physical and chemical properties of the soil increasing its drainage and aeration through the formation of underground galleries and transformation of organic matter (Brian, 1978). The effects of ants on nutrient immobilization and humification have been reported (Anderson and Flanagan, 1989; Lavelle *et al.*, 1992). The refuse piles made by soil ants increases the speed of mineralization (Folgarait, 1998).
- The porous soil made by ants increases the water holding capacity (Petal, 1978a).
- They improve the quality of soil by strengthening the inorganic nutrients N, P and K in the soil (Salem and Hole, 1968; Czerwinski *et al.*, 1969; Petal, 1978b; Mandel and Sorenson, 1982).
- Anthill aids in the nutrient cycling (Petal, 1992).
- Ants can disperse plant propagules (Wilson, 1992).
- Anthills facilitate the appearance of invasive plant species (Bucher, 1982; Folgarait *et al.*, 1996; Farji-Brener and Margutti, 1997) and sometimes change or quicken the course of plant succession (Jonkman, 1978).
- Honey bees are very important prey for certain group of vertebrates. Among birds Honey Buzzard, Bee eater and Drongo are opportunistic hunters benefitted by bees (Oldroyd and Nanork, 2009).

SUMMARY

As is quite evident from the past studies, in any wetland ecosystems, the main focus always remains on the water dependent organisms while the organisms that thrive in the surrounding are frequently neglected. As the Water birds along with the physico-chemical parameters of the three reservoirs selected has already been documented a small component of the terrestrial fauna (Terrestrial Birds and Insects) present in the surroundings of these ecosystems is considered in the present study. Due to the year round availability of water along with the ample amount of food in these habitats, these scrublands around wetlands have become good niches for large number of organisms. In the present study terrestrial bird fauna along with the invertebrate prey base, especially, insects have been investigated.

Chapter 1 – Terrestrial Birds

This chapter deals with the terrestrial birds inhabiting the scrubland around the three reservoirs. As is very well known, birds are the indicators of the health of any ecosystem. The presence of good diversity of terrestrial birds *i.e.* total 66 species of birds belonging to 26 families encountered over two year in the area suggests the potential of these scrubs to support various terrestrial species. The abundance rating of terrestrial birds indicates that very few species were abundant or common and majority of them were either uncommon or rare. The abundant or the common species include the generalist species that do not require any particular set of conditions and are able to exploit different kinds of habitats while the rare species are the specialist that require specific habitats for their survival.

The Similarity index among the three reservoirs indicates the influence of the macro climatic conditions as the reservoirs are located within a distance of 50 kms. The annual density was found to be highest at TIR while species richness around WIR, whilst the differences in the diversity index and Evenness were negligible among the three

reservoirs. When the comparison is made between the three reservoirs it was found that the species richness was highest at the largest reservoir - WIR due to availability of various microhabitats that supported large number of native species but in small numbers. On the other hand the density was highest at the smallest reservoir - TIR where the chances of the dispersal of the individuals present over a larger area are less. In addition, because of urban influence at TIR more generalist species are present in large number . When seasonal variations in the density and species richness of terrestrial birds are considered, post-monsoon and winter are found to be the most favourable seasons as the resources are abundant along with the moderately favourable climatic conditions. However, H' and Evenness were low at WIR during post-monsoon while at other two reservoirs during winter indicating that whichever species were present in these seasons occurred in moderate numbers.

The terrestrial birds encountered in the present study were divided into 11 groups according to their feeding guilds. Most of the terrestrial birds observed around three reservoirs belonged to the insectivorous feeding guild. They were either purely insectivores like Drongo, Bee-eater and swallows or they preferred insects in addition to other food materials like fruits, grains, nectar, *etc*. The annual density of these groups suggests the dominance of Graminivore at TIR, Frugivore at JIR while Insectivores at WIR. The differences in the dominance of different groups suggest the potential of each reservoir having different feeding guilds to support different groups.

The seasonal density of these groups reflects the seasonal changes in the resources available in the monsoon dependent semi-arid zone of Central Gujarat, India. It is observed that TIR is the most suitable habitat for Graminivores as these were present all throughout the year in larger numbers at this reservoir. Graminivore niche is created during winter at JIR while during post-monsoon at WIR. Due to presence of varied food resource in the form of dead cattle, mostly preferred by the crows, higher density of birds like crows were present at JIR which resulted in the overall higher Omnivores density.. Frugivores found JIR as the most suitable habitat among the three reservoirs surveyed as is shown by their highest density around JIR all throughout the year. Insectivores thrived best in post-monsoon over other seasons as this is the most favoured period for insects (Chapters 2-6) increasing their diversity as well as density. Insectivores + Frugivores dominated only during summer at TIR while had low density at other two reservoirs. At TIR Insectivores + Graminivores occurred in higher numbers during all the seasons except monsoon while they were more prevalent in winter at JIR and in both post-monsoon and winter at WIR. The differences in density of this group can be attributed to the more grains available at TIR compared to other two reservoirs. Lack of resources led to the inability of other groups to build up significant densities.

Chapter 2 - General Insects

Total 188 species of insects belonging to 9 orders were found during the study around the three reservoirs. Of these, 4 orders namely Odonata, Hemiptera, Lepidoptera and Hymenoptera which had higher species richness and contributed significantly to the insect density are considered as the major orders and discussed separately as chapters while other 5 orders, Orthoptera, Dicytoptera, Isoptera, Coleoptera and Diptera which had lower species richness were considered as the minor orders in the area. Of the five minor orders, Dicytoptera and Isoptera were represented by a single species each and did not contribute to the density and species richness, and also had very low percentage occurrence. Orthoptera represented by 8 species was rarely observed as they prefer grasslands and in the study area the grasses were sparse due to scrub. Coleoptera and Diptera, two of the largest orders of class Insecta in general had low representation as the scrub are not the suitable habitat for these groups of insects. The former is more prevalent in the forests and an undisturbed habitat while the latter has heterogenous preference hence in the absence of optimum resources habitat shifting is observed.

Among the three reservoirs the highest species richness was recorded at WIR in annual as well as seasonal representation with exception in monsoon when JIR had highest species richness due to the changes in the habitat at regional level.

The density of total insects present in the study, calculated by three different methods depending on the niche utilized, showed that among all the insects, those present on the ground have the highest density as these basically consist of the social forms like ants and termites that form huge colonies. The annual density of the Ground insects was highest at WIR while that of the Arboreal at TIR and Aerial at JIR. However, the seasonal differences for Ground and Arboreal insects showed their higher density in summer at TIR while in winter for WIR as well as JIR. These differences were mainly due to the population explosion of the Treehoppers and ants in winter and summer at the respective reservoirs. In case of Aerial insects, their density was found to be highest during summer at JIR and WIR while in post-monsoon at JIR and TIR. Aerial insect density was significantly influenced by the odonates rather than the butterflies.

Annual percentage occurrence clearly suggested dominance of the four major orders with maximum population contributed by the Odonates (Dragonflies and Damselflies) and butterflies at all three reservoirs. In the seasonal context Odonates dominated during summer as it is the flight period of many species of dragonflies while in monsoon Lepidopterans dominated due to the availability of the abundant food resources. In post-monsoon both these groups had higher percentage occurrence as it is the most favourable seasons for all the insects. In winter Hymenopterans showed their dominance with the presence of large populations of ants at the two smaller reservoirs while at WIR in this season too Lepidopterans dominated over all the insect orders. Hemiptera also showed highest percentage occurrence in winter when the Treehoppers were more abundant.

Chapter 3 – Odonata

As said earlier, Odonata was one of the dominant insect orders with 45 species belonging to 8 families and 2 sub-orders. All together, 27 species of dragonflies (Sub-order-Anisoptera) and 18 damselflies (Sub-order – Zygoptera) belonging to 4 families each were recorded around the three reservoirs. Their dominance in the study can be attributed to their life-cycle wherein the eggs are laid on the surface of water as the nymphs are aquatic. As the adult Odonates are aerial predators while the nymphs are the bio-control agents regulating the population of the mosquito larvae in the water, hence they are important ecologically. Among the two Odonates groups the density as well as diversity of dragonflies was high compared to damselflies. Dragonflies have better dispersal ability due to their well evolved flight mechanism while damselflies are weak fliers. Among the Anisopterans, family Libellulidae had the highest number of species while among Zygopterans family Coenagrionidae was a rich family in term of species. Family Protoneuridae was absent at TIR, while Aeshnidae and Cordulegasteridae in addition to the former at JIR. At WIR, Platycnemididae and Aeshnidae were not reported.

The common odonate species in the study area include *Brachythemis contaminate, Trithemis pallidinervis* and *Crocothemis servilia* which are known to have wide distribution in the Indian sub-continent. The similarity index for these flying species among the three reservoirs was moderate indicating the similarity in the macroclimatic conditions. Among the three reservoirs higher annual species richness was recorded around the undisturbed reservoirs implying that the odonates prefer undisturbed habitats. WIR - the largest habitat provided several micro-habitats for specialist species increasing the overall density. H' was also found to be high at the undisturbed habitats while evenness did not show much differences among the three reservoirs. The seasonal differences in the species richness as well as density suggests post-monsoon to be the most favourable season for odonates when the climatic conditions along with resource availability are maximum. H' did not show much seasonal variations at TIR and JIR except winter while at WIR variations were noted. Evenness was recorded to vary in a narrow range at TIR indicating uniformity in the population while at JIR it dropped non-significantly in winter and at WIR in summer manifesting the dominance of some species during the season.

With reference to the annual percentage occurrence, family Libellulidae was the dominant family at the three reservoirs followed by Coenagrionidae. Other families had very low representation. This was mainly due to the presence of only one or two species representatives of all families recorded. The seasonal percentage occurrence also suggests the dominance of Libellulidae followed by Coenagrionidae in all the seasons at the three reservoirs. Although Gomphidae had low percentage occurrence it was present all throughout the year at all reservoirs. Other families had low percentage occurrence and were absent during different seasons of the year.

Chapter 4- Hemiptera

It is the order of insects consisting of both ecologically harmful as well as useful species of bugs either plant sap feeders or predators inhabiting aquatic or terrestrial systems. Most of the aquatic bugs along with the predatory bugs are good bio-control agents while many homopterans are the pest of vegetation. In the present study, only 19 Hemipterans were recorded which are classified in 14 different families. As few species were recorded for this order the annual similarity index was high between three reservoirs of semi-arid zone of Gujarat. However the seasonal similarity index fluctuated implying the influence of the changes at the micro climate level with changes in the seasons. The annual species richness as well as density was found to be highest at WIR where diverse micro habitats are available. Overall low H' and Evenness recorded for the three reservoirs reveal the mono dominance of *Oxyrhachis tarandus.* The seasonal differences in species richness and density clearly signify winter as the most favourable season for hemipterans when the bushes are denser providing appropriate niche for these arboreal insects. Although overall low H' and Evenness were recorded for this group, comparatively higher H' and Evenness in winter suggests the ability of the habitats to support hemipterans.

The annual percentage occurrence clearly implies Membracidae to be most dominant hemipteran family that depends on plant varieties like *Acacia* that are abundant around the three reservoirs. Other families with good percentage occurrence include Gerridae and Alyerodidae which include some of the common hemipterans. The seasonal percentage occurrence also indicates the dominance of family Membracidae in all the seasons at JIR, while in all seasons except monsoon at TIR and during post-monsoon and winter at WIR. Their year round dominance at JIR can be attributed to availability of the appropriate arboreal niche at the reservoir where trees are present on the earthen dam itself and vegetation on the dam is not removed as part of management plan. At TIR, in monsoon, as the water level increases, the surface area available for the water strider, *Gerris sp.* also increases validating Gerridae as dominant family over Membracidae. At WIR, no family was found to dominate due the micro-habitat characteristic supporting more than one families.

Chapter 5: Butterflies

Butterflies belong to the order Lepidoptera of Class Insecta. In the present study 49 species of butterflies belonging to 4 families were recorded. Of these, the family Nymphalidae was the richest family with Plain tiger (*Danaus chrysippus*) as the most common species followed by Pieridae, Lycaenidae and Papillionidae. Among the three reservoirs, family Nymphalidae was more common at WIR while Pieridae at TIR and JIR. When the butterflies were rated for their abundance, only a single species *D. chrysippus* was found to be abundant at all three reservoirs. Most of the species were either rare or uncommon. The similarity among the reservoirs was moderately high suggesting the resemblance in the macro habitats for these fliers which can explore wider area due to their flying abilities. When seasonal similarity is considered it is seen that due to the hostile conditions of summer and winter, many species were not present leading to low similarity index compared to the wet seasons of the year.

The annual species richness of butterflies was found to be highest at the largest of the three reservoirs, WIR, while the density was highest at the smallest of three, the TIR. The larger area supports more species but due to the size the rate of dispersion is high leading to low density while in smaller area the rate of dispersion of few species is low increasing their site fidelity. H' was higher at the two undisturbed reservoirs JIR and WIR while evenness did not show much variations amongst the three reservoirs. Highest species richness observed in post-monsoon at all three reservoirs suggests creation of favourable habitats to support wider variety of butterfly species. During this season density was also high at the smaller two reservoirs while in winter at WIR indicating the importance of the vegetation to the butterflies. H’ also showed the same scenario as the above two parameters with highest in post-monsoon. Evenness was almost same in all the seasons at WIR and JIR while at TIR it declined in post-monsoon.

The annual percentage occurrence suggests the dominance of Nymphalidae at all three reservoirs due to the presence of highest number of species, while family Pieridae also had nearly same percentage occurrence at JIR indicating the favourability of the habitats for the Pierids. The seasonal percentage occurrence also indicates the dominance of Nymphalidae in summer and post-monsoon at all reservoirs along with Pieridae in summer at JIR. This clearly implies the results of recent modifications in phylogenetic classification where several families are brought under family Nymphalidae. In monsoon Pieridae was the dominant family at TIR as well as JIR as these sun lovers are more common during the monsoon after rain showers. In winter Lycaenidae was found to dominate as these small butterflies try to survive in the unfavourable winter when the larger butterflies requiring more resources are absent.

Chapter 6 – Hymenoptera

Hymenoptera is the order that includes ants, bees and wasps. This order is having the highest density in the area due to the presence of various species of ants. In the present study total 36 species of hymenopterans belonging to 6 families and a single sub-order Apocrita were recorded. Most of the species recorded belonged to the single family Formicidae comprising of ants with *Camponotus compressus* the most common hymenopteran. The other common ant species include *Solenopsis invicata*, *Monomorium minimum* and *Oecophylla smargdina* while the bee species was *Bombus psythrus (*Apidae) and wasp *Ropalidia marginata (*Vespidae). Overall low similarity index was noted between the reservoirs due to the habitat differences at the regional level. Wasp species increased the species richness at the two undisturbed reservoirs. The highest density at WIR can be due to the larger area available for the ants to build their nests as well as the stiffness of the earthen dam due to its age. H' was also higher at WIR compared to other two reservoirs while the evenness was low for all three reservoirs due to mono-dominance of *C. compresses.* The seasonal variations in the species richness suggests winter to be favourable season at TIR while summer and monsoon at JIR and major part of the year at WIR indicating that the hymenopterans prefer wide spectrum of climatic conditions. The density of the hymenopterans was recorded to be highest during summer at TIR where more ground nesting ants were encountered while at JIR and WIR during winter due to bushes providing more surface area along with the shade that is preferred for colonization by arboreal ants. Overall lower H' for hymenopterans was noted for all three reservoirs, however among these higher values noted in monsoon at TIR and summer at JIR and WIR implies the low dominance of *C. compresses* during these seasons. However, Evenness was low all throughout the year due to the occurrence of mono-dominant species.

The annual as well as seasonal percentage occurrence shows the dominance of Formicidae as it is the largest family of the present study. Apidae was the second dominant family for all the reservoirs in annual as well as seasonal comparison as it includes one of the commonest bees in the Indian climatic conditions. Vespidae and Xylocopidae had higher percentage occurrence at JIR suggesting that they prefer areas with low human disturbance and unmodified vegetation.

Hence the present study indicates that the scrublands around monsoon dependent wetlands are good habitats for wide variety of terrestrial fauna like birds and insects. Though the terrestrial birds occur in low numbers compared to wetland birds, with insect density and diversity they form an important component of this ecosystem at the eco-tone between land and water.

GENERAL CONSIDERATION

India being a country with monsoon type of climate, people depend on rains for their needs for water. Gujarat, being located in the semi arid and arid zone of India, has been facing the scarcity of water. To avoid severe water scarcity during rest of the year, rulers of the erstwhile states as well as present day administrators have constructed various reservoirs over several decades to store rain water that could be used for various human as well as agricultural needs. The older reservoirs satisfy the needs of the local people whereas the water from the recently developed mega reservoirs is diverted to the older reservoirs increasing their hydro period. Two such local reservoirs having Narmada inundation *i.e.* Wadhwana Irrigation Reservoir (WIR) a Nationally Important Wetland and the largest of the three surveyed and Timbi Irrigation Reservoir (TIR) smallest of the three and closer to the Vadodara city along with a reservoir without Narmada inundation and no major disturbance, Jawla Irrigation Reservoir (JIR) were selected for the present study. The human disturbances as well as the land matrix around the three reservoirs are also different influencing the flora and fauna present differently. These reservoirs are utilized by high number of waterfowls attributed to the increased hydro period after the Narmada inundation. The results of studies by Deshkar (2008) established the potential of WIR to be considered as an IBA and one of the Ramsar site in future years and hence the study of Terrestrial birds and insect diversity was initiated in the area. On the other hand as TIR also supports large number of waterfowls, Deshkar (2008) has stressed on its being declared as a Nationally important Wetland and need for evaluation of its potential to supports other organisms.

Under the concept of conservation of biodiversity, the documentation of the species present at the grass root level is essential. The present study is an important step in this direction of documentation of terrestrial birds and insects biodiversity present around the three reservoirs. This study enumerates the organisms that constitute important link in the food chain of the aquatic ecosystem like wetlands and its surrounding areas. The flora and fauna are the essential elements that make up an ecosystem. The floral and the faunal components of many habitats like the forest, desert, coastal habitats, *etc.* the attractive habitats, that support the larger organisms have been extensively documented while the wetlands have been ignored. However, after the Ramsar convention together with the Convention on Biodiversity these ecosystems have also started receiving importance. In the selected wetlands, Water birds, the most important visible organisms of the system have been documented with their diversity *eg.* Deshkar (2008) and Rathod (2009) Hence, a step further, documentation and seasonal changes in the density and diversity of the Terrestrial birds and insects inhabiting the surrounding scrubland of the three reservoirs was initiated in the present study.

Birds are the most charismatic vertebrates having the extra ordinary ability of flight. This ability makes them capable of responding to the adverse circumstances by flying away to distant locations and hence they are considered the ecological indicators of the health of ecosystems. Birds feed on varied kind of plant and animal matter like seeds and fruits, and invertebrates along with vertebrates, carcasses as well as garbage. Insect forms one of the basic food items for many birds. Hence the diversity of the insects found in the area was also assessed. The present study focused on the terrestrial birds and their correlation with the food availability mainly insects.

It is known that insects belong to the most diverse classes that have conquered all possible habitats on the planet earth except Oceans and Poles. They also possess exceptionally excellent ability to fly and hence have colonized in large spectrum of climatic conditions. They are important from the ecological point of view as they are useful in the evaluation of landscapes for biological conservation and act as one of the main prey base for large number of vertebrates and help in the successful management of the food chain.

When the density and diversity of birds is considered (Chapter 1) it is noted that majority of the birds depend on insects as their food in some stage of their life. Hence, the insect diversity present around the three reservoirs has been considered in Chapter 2. On the basis of this, four orders of Class Insecta were found to be major groups in the area and hence these were considered in more details. The first group includes Dragonflies and Damselflies (Chapter 3) of Order Odonata. These are the water dependent insects as their nymphal stages are completely aquatic and the adults are terrestrial - most successful fliers among all the insects. These were found in greater numbers around the three reservoirs. The next common group was Order Hemiptera (Chapter 4). This is the order consisting of bugs that may be either aquatic or terrestrial. The aquatic bugs were found in the water of the reservoirs while the terrestrial bugs that are mainly plant sap feeders were found on the scrub bushes present on the earthen dam. Lepidoptera, the Butterflies and moths, one of the most flourished insect groups due to their beautiful colours was the next group studied in detail. As most of the moths are nocturnal, they were sparse in this diurnal studies, hence only butterflies being diurnal were considered (Chapter 5). Order Hymenoptera, includes ants, bees and wasps that colonize wide range of habitats formed another major group of insects around the reservoirs. Hence they were also considered in detail (Chapter 6).

Terrestrial birds were represented by 66 species, of which 58 species each were observed at TIR and WIR while 52 at JIR. Of these majority of the birds fed principally on insects. Among the three reservoirs, maximum bird species richness was observed at WIR while maximum bird density at TIR. Shannon Weiner diversity index and Evenness were maximum at WIR and JIR respectively. The seasonal illustration clearly showed the differences at local level depending on size of reservoir, proximity to urban conditions, Narmada inundation and land matrix.

According to the food that they feed on, the terrestrial birds observed were divided into 11 different groups. Among all these groups, insectivores had the highest density at WIR, while the Frugivore although represented by a single species *Psittacula krameri* had the highest density at JIR and Graminivore at TIR with most of the species having highest density in post-monsoon or winter and only Frugivore at WIR and Insectivore + Frugivore at TIR in summer.

Among insects total 188 insects belonging to 9 insect orders were observed around the three reservoirs with Odonata, Hemiptera, Lepidoptera and Hymenoptera constituting more than 80% of the total insect density and diversity. Hence other orders were considered as minor orders. Many of the species were shared between TIR and JIR mainly due to long distance fliers like Butterflies. Among the three reservoirs, annual maximum species richness was recorded at WIR while annual maximum density for the ground and flying insects at WIR and for arboreal insects at TIR. Percentage occurrence is a comparative measure and hence if percentage of one group increases that of the other decreases. The annual percentage occurrence suggests that Lepidoptera was dominant group at TIR while Odonata at JIR and WIR. The seasonal percentage occurrence indicates that Odonata and Hymenoptera had highest percentage occurrence in summer, Hemiptera in winter at all the three reservoirs while Lepidoptera in Post-monsoon at TIR and WIR and in monsoon at JIR. Other groups being less represented had low percentage occurrence.

45 species of Odonata belonging to 8 families (4 of Zygoptera – Damselflies and 4 of Anisoptera - Dragonflies) were observed around the three reservoirs. Coenagrionidae was the most common damselfly family while Libellulidae the dragonfly family. Maximum 37 species belonging to 5 families of Odonates were recorded at JIR while at TIR and WIR 35 species each belonging to 7 and 6 families respectively were recorded. Maximum similarity index of Odonata was between TIR and JIR. The annual study

suggests presence of maximum species richness of Odonates at JIR while density and Shannon Weiner Diversity index H’ at WIR. Evenness was almost same for TIR and WIR. The seasonal differences suggests that post-monsoon is the most favourable season for Odonates with highest species richness, density and H’ in the semi arid zone of Gujarat, India. The percentage occurrence of family Libellulidae was highest in annual as well as seasonal evaluations. However, among the damselflies family Coenagrionidae had higher percentage occurrence at the three reservoirs. This family was more common in winter as compared to other seasons of the year.

Hemiptera, although considered as the major order, was represented by only 19 species around the reservoirs. However, these 19 species belonged to 14 families. Among these the most dominant family was Membracidae. The similarity of hemipterans was found to be maximum 0.8 between TIR and JIR. The annual species richness and density were maximum at WIR, H’ showed no variations among the three reservoirs while Evenness was maximum at JIR. The seasonal differences show all the four indices *i.e.* species richness, density, H’ and Evenness for Hemiptera to be maximum in winter except the density at TIR which was maximum in summer. Membracidae was the most dominant family with respect to percentage occurrence too at all the three reservoirs. The seasonal percentage occurrence also showed highest occurrence of Membracidae in all the seasons at all the three reservoirs except the dominance of Gerridae in Monsoon at TIR and WIR.

Coming to the next major group, total 49 species of Butterflies belonging to 4 families were observed around the three reservoirs. Of these 34 species were present at TIR, 36 at JIR and 42 at WIR. Maximum similarity of 0.75 was observed between TIR and JIR. The annual and seasonal percentage occurrence suggests that Nymphalidae is the most dominant family at all the three reservoirs especially in summer and post-monsoon while Pieridae at TIR and JIR and Lycaenidae at WIR in monsoon. However, in winter, Lycaenidae was dominant at TIR and JIR and Nymphalidae at WIR.

Hymenoptera that includes ants, bees and wasps, was represented by 36 species belonging to 6 families (Formicidae,Vespidae, Sphecidae, Chrysididae, Xylocopidae and Apidae) around the three reservoirs. Of these, 25 species were found around WIR, 20 around TIR and 23 around JIR. Formicidae was the most dominant family represented with maximum number of ant species. This group had overall low similarity, with 55% common species between JIR and WIR. The annual as well as seasonal percentage occurrence showed the dominance of Formicidae at the three reservoirs.

The study indicates that among all varied insects present around the three reservoirs in the semi arid zone of Gujarat, India, four insect orders were found to be the major orders. Other insects although present did not had the potential to colonize the habitats around the water bodies successfully.

The results of the study indicate that though the abundance of terrestrial birds around wetland is not very high as compared to that of water birds their presence is ubiquitous. The availability of the food resources along with the suitable climatic features encourages the colonization of these varied species in the area. The scrublands and the agricultural fields also provide good opportunities to the insects for feeding as well as resting so good diversity of insects were found in the area. The basic aim of the study to document the terrestrial bird fauna around the three reservoirs along with the insect food base available in the area has been duly fulfilled. The large variety of birds with insects available to them as their prey base proves that habitats around wetlands also have good potential to be important habitats for their colonization. The present study also adds significantly to local biodiversity register if required and it is expected to help in constituting the management and conservation efforts of different wetlands in the semi arid zone of Central Gujarat with biodiversity point of view.

When the Pearson correlation of species richness and density of different groups studied is considered it manifested that (Table C, D, E).

- Species richness of odonates influence the total insect species richness maximally which was mainly contributed in the post-monsoon.
- Hemiptera was the prime determinant of the arboreal insect density in summer and winter the dry seasons of the year at the two smaller reservoirs. The species richness of this group was also noted to have significant effect on the arboreal insect density.
- The density of the ground insects was mainly contributed by the ants in all the seasons of the year at the two smaller reservoirs while the effect was manifested mainly during winter at the larger reservoir.
- The butterfly density also influenced the aerial insect density in the annual comparison.
- In monsoon the density of the aerial insects was influenced by the species richness of butterflies.
- The number of total insect species was positively correlated with the species richness of Hemipterans which needs further investigation.
- In summer species richness of birds did not show any correlation with the insect diversity while in winter it was variably correlated with the species richness of hemiptera.
- The correlation of the Terrestrial birds present around the three reservoirs with the different orders of insects that may serve as prey base for them have been attempted to find out if there exists any absolute dependency. When the correlation were made among the two groups (Terrestrial Birds and Insects) the influence of the species richness and density of birds was minimum on the insect density and diversity in annual as well as all the seasons of the year. At JIR and WIR species richness of the birds was negatively correlated with the butterfly

density indicating that the aerial species of birds may not be predating on the butterflies at the undisturbed areas where food resources are abundant

Future Aspects of the Study

As the importance of water bodies in the semi arid zone of Central Gujarat is well recognized and most of the components related to the water have already been documented, the present study was initiated to add further information regarding terrestrial birds and insect diversity in the area. This being the first important documentation for the scrubland around irrigation reservoirs has opened path for the studies of following aspects.

- Documentation of other vertebrate and invertebrate fauna present in the area.
- Study of the breeding activities of terrestrial birds in the area.
- The study of the interdependence of various fauna on each other in semi arid zone.
- Lifecycle of various insect groups in the area and their dependency on water, vegetation and other climatic conditions.
- Detailed study of the food and breeding of the different insects present in the area.
- Influence of Narmada inundation and anthropogenic activities on the different fauna present.

Table C. Correlation of species richness and density of various insect groups and birds at TIR

	DHy	SRHy	DBu	SRBu	DH	SRH	DO	SRO	DPI	DBI	DQI	SRI	DB	SRB
Annual														
SRB	.272	-.043	.109	-.146	-.020	-.336*	.148	.084	.087	.024	.208	.551**	.553**	1
DB	.009	.264	-.175	-.340*	.294	.205	.047	-.098	-.246	.275	-.010	.091	1	
SRI	.166	-.007	.404**	.370*	-.260	-.478**	.066	.616**	.383*	-.192	.176	1		
DQI	.929**	.187	-.032	-.029	.043	.072	.027	-.030	.028	.121	1			
DBI	.361*	.228	-.195	-.202	.945**	.622**	-.095	-.285	-.162	1				
DPI	.014	-.018	.589**	.629**	-.135	-.234	.094	.466**	1					
Summer														
SRB	-.233	.147	-.406	-.290	-.327	-.232	.307	-.104	-.277	-.323	-.151	-.259	.297	1
DB	.059	.406	-.393	-.341	.583*	.508	.302	.344	.666*	.492	-.089	.291	1	
SRI	.803**	.651	.403	.147	.678*	.798**	-.182	.033	.267	.725**	.642*	1		
DQI	.948**	.675*	.199	-.089	.105	.422	-.115	-.132	-.243	.203	1			
DBI	.498	.482	.267	.407	.975**	.874**	-.188	.355	.626*	1				
DPI	-.025	.148	-.132	-.021	.679	.511	.265	.730**	1					
Monsoon														
SRB	.650*	-.648*	-.725*	-.611	-.289	-.577	-.389	.536	-.050	-.032	.689	-.759*	.632*	1
DB	.559	-.465	-.509	-.352	-.286	-.469	-.327	.383	-.080	-.033	.595	-.466	1	
SRI	-.382	.542	.216	.116	.159	.311	.078	-.424	-.310	.292	-.447	1		
DQI	.983**	.221	-.729*	-.374	-.395	-.407	-.590	.564	.229	.357	1			
DBI	.505	.413	-.159	.012	.273	.398	-.288	-.152	.094	1				
DPI	.209	.575	.376	.676*	.174	.493	.332	-.292	1					
Post-monsoon														
SRB	.650*	-.648*	-.725*	-.611	-.289	-.577	-.389	.536	-.050	-.032	.689	-.759*	.632*	1
DB	.559	-.465	-.509	-.352	-.286	-.469	-.327	.383	-.080	-.033	.595	-.466	1	
SRI	-.382	.542	.216	.116	.159	.311	.078	-.424	-.310	.292	-.447	1		
DQI	.983**	.221	-.729*	-.374	-.395	-.407	-.590	.564	.229	.357	1			
DBI	.505	.413	-.159	.012	.273	.398	-.288	-.152	.094	1				
DPI	.209	.575	.376	.676*	.174	.493	.332	-.292	1					
Winter														
SRB	.624*	-.063	-.269	-.175	.428	-.682*	-.430	.068	-.376	.721**	-.092	.589*	.614*	1
DB	.036	.201	-.194	-.367	.241	-.398	-.470	-.106	-.112	.298	.029	.295	1	
SRI	.552	-.047	-.539	-.257	.260	-.401	-.289	.321	-.509	.568	.345	1		
DQI	.349	.418	.096	-.133	-.201	.409	-.332	.117	.135	-.165	1			
DBI	.518	-.074	-.552	-.101	.746**	-.478	-.380	.098	-.644*	1				
DPI	-.399	.645*	.931**	.376	-.505	.488	-.165	-.389	1					

Table D. Correlation of species richness and density of various insect groups and birds at JIR

	DHy	SRHy	DBu	SRBu	DH	SRH	DO	SRO	DPI	DBI	DQI	SRI	DB	SRB
Annual														
SRB	.326	.031	-.028	-.381*	-.334*	.063	.128	.118	-.138	.330*	.321*	.120	.472**	1
DB	.083	-.325*	-.306	-.471**	.395*	.291	-.123	.029	-.296	.401*	.053	-.025	1	
SRI	.230	-.337*	.150	.039	.008	-.164	.104	.800**	-.088	-.117	.222	1		
DQI	.992	.023	.006	-.085	.045	.119	.456**	.254	.191	.018	1			
DBI	.079	.084	-.027	-.073	.777**	.569**	-.173	.017	.112	1				
DPI	.193	.456**	.330*	.419**	.053	.069	.364*	-.104	1					
Summer														
SRB	.275	.526	.186	-.213	.448	.448	.258	.066	.302	.563	.197	.285	.567	1
DB	.032	.023	-.266	-.702*	-.013	.044	.025	.192	-.121	.101	.013	.001	1	
SRI	.334	.740**	.643*	.368	.391	.719**	.658*	-.479	.626*	.415	.286	1		
DQI	.990**	.258	-.062	-.017	-.047	.239	.246	-.241	.330	.119	1			
DBI	.013	.337	.172	.057	.964**	.729**	.305	.119	.512	1				
DPI	.377	.687*	.354	.537	.582*	.709**	.598*	-.446	1					
Monsoon														
SRB	.009	-.057	-.423	-.805*	.187	-.294	-.103	.000	.-.603	-.188	.154	-.272	.622	1
DB	-.034	-.209	-.682	-.691	.651	.154	-.389	-.004	-.709*	-.004	-.014	-.517	1	
SRI	-.259	.748*	.653	.245	-.548	.293	.283	-.258	.584	.291	-.409	1		
DQI	.915**	.109	-.325	-.276	.032	.068	.290	-.059	-.253	-.047	1			
DBI	.346	.379	.402	.383	.148	.658	-.444	-.371	-.050	1				
DPI	-.242	.395	.800*	.567	-.303	-.014	.052	-.142	1					
Post-moonsoon														
SRB	.163	.415	.236	-.044	-.473	-.629	.242	.420	-.505	-.417	.224	.417	.370	1
DB	-.435	.297	-.290	-.131	.349	-.071	-.168	-.095	-.709	-.009	-.525	-.294	1	
SRI	.023	.709	-.182	-.438	-.856*	-.194	.275	.772*	-.163	-.410	.233	1		
DQI	.974	-.451	.631	.429	-.432	-.482	.366	-.118	.132	-.662	1			
DBI	-.593	.001	-.393	-.225	.602	.601	-.695	-.244	.557	1				
DPI	.166	-.341	.224	.317	.096	.158	-.279	-.175	1					
Winter														
SRB	.339	-.618*	.015	-.288	.404	-.118	.181	-.342	.008	.364	.332	.461	.352	1
DB	-.171	-.713*	-.650*	-.449	.567	.112	-.072	-.265	-.180	.515	-.188	.166	1	
SRI	.271	-.199	.037	-.292	-.198	-.274	-.448	.232	.022	-.235	.272	1		
DQI	.998**	.149	.164	.115	-.088	.023	.713*	.229	.689*	-.122	1			
DBI	-.107	-.409	-.050	-.090	.858**	-.008	-.214	-.202	-.343	1				
DPI	.683*	.452	-.013	.228	-.200	-.202	.608*	.333	1					

Table E. Correlation of species richness and density of various insect groups and birds at WIR

	DHy	SRHy	DBu	SRBu	DH	SRH	DO	SRO	DPI	DBI	DQI	SRI	DB	SRB
Annual														
SRB	.265	-.185	.404**	.356*	.210	.233	.134	.087	-.259	.427**	.235	-.154	.503**	1
DB	.024	-.272	.124	.413**	.012	.034	.212	.099	-.005	.036	-.126	-.149	1	
SRI	-.147	.202	-.209	.131	-.395	-.044	.065	.618**	.133	-.136	-.124	1		
DQI	.575**	.304*	.600**	.363*	.241	.325*	-.142	-.072	-.212	.256	1			
DBI	.384**	.097	.274	.023	.398**	.466**	-.160	.108	-.276	1				
DPI	-.201	-.202	-.255	-.171	.-139	-.226	.061	-.210	1					
Summer														
SRB	-.333	-.074	-.337	-.225	-.128	-.146	.544	.051	-.361	.180	.417	-.368	.431	1
DB	-.363	-.240	-.328	-.167	.478	.158	-.105	.274	.041	.468	-.077	-.174	1	
SRI	.014	.445	.294	-.220	.043	.230	-.329	.464	.435	-.464	-.534	1		
DQI	-.175	-.142	-.228	.111	-.320	-.015	.481	-.241	-.321	-.124	1			
DBI	.038	.009	-.130	.392	-.018	.210	-.039	-.065	-.313	1				
DPI	-.396	-.265	.114	-.309	.395	-.083	-.143	.155	1					
Monsoon														
SRB	.187	-.427	-.011	.011	-.642*	.313	-.107	.274	.464	.208	.194	-.068	.291	1
DB	.407	-.379	.095	.389	.114	.524	.388	-.034	.545	-.141	.308	-.318	1	
SRI	.114	.346	.426	.370	-.199	-.168	-.374	-.397	-.207	-.393	.295	1		
DQI	.891**	.313	.676*	.674*	-.297	-.004	-.128	-.104	.086	-.259	1			
DBI	.037	.152	.071	-.381	.185	.279	.502	.159	-.200	1				
DPI	-.074	-.088	.105	.440	-.401	.576	.182	-.028	1					
Post-monsoon														
SRB	.514	.330	.122	.477	.092	.683*	.065	.162	.229	.483	.453	.185	.764*	1
DB	.173	.203	.314	.184	-.011	.656*	-.334	.172	.069	.446	.103	.177	1	
SRI	.577	.588	.199	.076	.213	.497	.048	.696*	-.150	.197	.402	1		
DQI	.818**	.820*	.096	.465	.696*	.609	.107	.326	.069	-.038	1			
DBI	.334	.090	-.201	.384	-.474	.197	-.083	-.292	.486	1				
DPI	.031	-.320	-.658*	-.700*	-.267	-.281	.516	-.648*	1					
Winter														
SRB	.239	.310	.278	.725*	-.177	.609*	.054	.243	-.253	-.186	.422	-.510	-.039	1
DB	-.304	.050	-.115	.282	-.544	-.510	-.317	-.239	-.328	-.360	-.051	.229	1	
SRI	-.584*	-.247	-.568	-.467	-.268	-.597*	-.260	-.608*	.152	-.024	-.583*	1		
DQI	.647*	.132	.625*	.343	.410	.142	.252	.513	-.148	.170	1			
DBI	.240	.183	.206	-.423	.857*	-.103	-.263	.017	.057	1				
DPI	-.119	-.259	.093	-.325	.124	.055	.560	-.383	1					

ANNEXURES

Annexure 1
List of the Terrestrial Birds observed at the three reservoirs with their feeding Habits

Sr. No.	Common Name	Scientific Name	Food	TIR	JIR	WIR
I	**Family: Columbidae**					
1	Blue Rock Pigeon	*Columba livia*	G	* (A)	* (U)	* (C)
2	Laughing Dove/Little Brown Dove	*Streptopelia senegalensis*	G	* (A)	* (F)	* (F)
3	Spotted Dove	*Streptopelia chinensis*	G		* (R)	* (C)
4	Ringed Dove/Eurasian collared Dove	*Streptopelia decaocto*	G	*(F)	* (R)	
II	**Family: Psittacidae**					
5	Roseringed Parakeet	*Psittacula krameri*	F	* (A)	* (A)	* (A)
III	**Family: Cuculidae**					
6	Pied Crested Cuckoo	*Clamator jacobinus*	I+F	* (R)		* (R)
7	Asian Koel	*Eudynamys scolopacea*	F+O	* (F)	* (U)	* (C)
8	Greater Coucal	*Centropus sinensis*	C	* (U)	* (C)	* (A)
IV	**Family: Strigidae**					
9	Spotted Owlet	*Athene brama*	C		* (R)	
V	**Family:Apodidae**					
10	House Swift	*Apus affinis*	I	* (R)	* (U)	* (R)
11	Asian Palm Swift	*Cypsiurus balasiensis*	I	* (R)		* (R)
VI	**Family: Meropidae**					
12	Blue tailed Bee-eater	*Merops philippinus*	I	* (U)	* (U)	* (F)
13	Small Bee-eater	*Merops orientalis*	I	* (R)	* (U)	* (F)
VII	**Family: Coraciidae**					
14	Indian Roller	*Coracias benghalensis*	I+C	* (R)	* (R)	* (R)
VIII	**Family: Upupidae**					
15	Common Hoopoe	*Upupa epops*	I	* (U)	* (R)	* (R)
IX	**Family: Capitonidae**					
16	Crimson-breasted Barbet	*Megalaima haemacephala*	I	* (R)	* (R)	* (U)
X	**Family:Picidae**					
17	Lesser Flamebacked woodpecker	*Dinopium benghalense*	I		* (R)	
XI	**Family:Alaudidae**					
18	Rufous tailed Finch-lark	*Ammomanes phoenicurus*	I	* (F)	* (R)	* (F)
19	Ashy Crowned sparrow lark	*Eremopterix grisea*	I+G	* (U)	* (U)	* (U)
XII	**Family: Hirundinidae**					
20	Dusky Crag Martin	*Hirundo concolor*	I	* (U)		* (R)
21	Barn Swallow	*Hirundo rustica*	I	* (U)	* (R)	* (F)
22	Wiretailed Swallow	*Hirundo smithii*	I	* (C)	* (U)	* (C)
23	Redrumped Swallow	*Hirundo daurica*	I	* (R)		* (R)
XIII	**Family: Oriolidae**					
24	Eurasian Golden Oriole	*Oriolus oriolus*	I+F		* (R)	
XIV	**Family: Laniidae**					
25	Baybacked Shrike	*Lanius vittatus*	C	*(R)		*(R)
26	Long-tailed Shrike	*Lanius schach*	C	* (U)	* (R)	* (F)
XV	**Family: Dicruridae**					
27	Black Drongo	*Dicrurus macrocercus*	I	* (A)	* (C)	* (A)
28	Ashy Drongo	*Dicrurus leucophaeus*	I			* (R)
XVI	**Family: Sturnidae**					
29	Brahminy Starling	*Sturnus pagodarum*	I+F	* (F)	* (U)	* (F)
30	Rosy Starling	*Sturnus roseus*	I+F	* (U)	*(R)	* (R)

31	Common Myna	*Acridotheres tristis*	O	* (C)	* (A)	* (A)
32	Bank Myna	*Acridotheres ginginianus*	O	* (F)	* (R)	* (F)
XVII	**Family: Corvidae**					
33	Indian Tree Pie	*Dendrocitta vagabunda*	O			* (R)
34	House Crow	*Corvus splendens*	O	* (A)	* (A)	*(A)
35	Jungle Crow	*Corvus macrorhynchos*	O	* (U)	* (U)	* (R)
XVIII	**Family: Pycnonotidae**					
36	Red Vented Bulbul	*Pycnonotus cafer*	I+F	* (F)	* (F)	* (F)
XIX	**Family: Muscicapidae**					
37	Common Babbler	*Turdoides caudatus*	O	* (U)		* (R)
38	Large Grey Babbler	*Turdoides malcolmi*	O	* (F)	* (F)	* (F)
39	Jungle Babbler	*Turdoides striatus*	O	* (U)		* (F)
40	Bluethroat	*Luscinia svecicus*	I	* (R)	* (R)	
41	Oriental Magpie Robin	*Copsychus saularis*	I	* (R)		* (R)
42	Common Stone Chat	*Saxicola torquata*	I	* (U)	* (U)	* (U)
43	Indian Robin	*Saxicoloides fulicata*	I	* (A)	* (R)	* (C)
44	Paddyfield Pipit	*Anthus rufulus*	I	* (C)	* (R)	* (C)
45	Common chiffchaff	*Phylloscopus collybita*	I	*(F)	* (C)	* (C)
XX	**Family: Monarchinae**					
46	Plain Prinia	*Prinia inornata Sykes*	I	* (R)	* (R)	* (U)
XXI	**Family: Motacillidae**					
47	Yellow Wagtail	*Motacilla flava*	I	* (F)	* (R)	* (C)
48	Pied or White Wagtail	*Motacilla alba*	I	* (R)		* (F)
49	White browed wagtail	*Motacilla maderaspatensis*	I	* (R)		* (U)
XXII	**Family: Nectariniidae**					
50	Purple Sunbird	*Nectarinia asiatica*	N	* (R)	*(F)	* (U)
51	Purple rumped Sunbird	*Nectarinia zeylonica*	N		* (R)	* (R)
XXIII	**Family: Ploceidae**					
52	House Sparrow	*Passer domesticus*	G	* (F)	* (R)	* (U)
53	Baya Weaver	*Ploceus philippinus*	I+G	* (F)	* (R)	* (U)
54	Streaked Weaver	*Ploceus manyar*	I+G	* (R)	* (R)	* (R)
55	Red Munia	*Amandava amandava*	G	* (U)	* (U)	* (U)
56	Scaly breasted Munia	*Lonchura punctulata*	G	* (R)	* (R)	
57	Silverbill /Whitethroated Munia	*Lonchura malabarica*	G	* (U)	* (R)	
XXIV	**Family: Emberizidae**					
58	Red headed Bunting	*Emberiza bruniceps*	G	* (U)	* (R)	* (R)
59	Black headed Bunting	*Emberiza melanocephala*	G	* (R)	* (R)	* (R)
XXV	**Family: Accipitridae**					
60	Osprey	*Pandion haliatus*	BOP	* (R)	* (R)	* (F)
61	Shikra	*Accipiter gentilis*	BOP		* (R)	
62	Black Kite	*Milvus migrans*	BOP	*(U)	* (R)	* (R)
63	Black shouldered Kite	*Elanus caeruleus*	BOP	* (R)	* (R)	* (R)
64	Eurasian Marsh Harrier	*Circus aeruginosus*	BOP	* (U)	* (R)	* (F)
XXVI	**Family: Phasianidae**					
65	Indian Peacock	*Pavo cristatus*	O	* (C)		* (R)
66	Grey Francoline	*Francolinus pondicerianus*	I+G	* (C)	* (F)	* (F)

Annexure 2
List of the Insects observed at the three reservoirs

Sr. No.	Common Name	Scientific Name	TIR	JIR	WIR
I	**Order : Odonata**				
A	*Sub-order - Zygoptera*				
i	**Family: Coenagrionidae**				
1	Coromandel Marsh Dart	*Ceriagrion coromandelianum*	*	*	*
2	Blue Grass Dartlet, Blue Sprite	*Pseudagrion microcephalum*	*	*	*
3	Golden Dartlet	*Ischnura aurora*	*	*	*
4	Senegal golden Dartlet	*Ischnura senegalensis*	*	*	*
5	Pigmy Dartlet	*Agriocnemis pygmaea*	*	*	*
6	Black marsh dart	*Onychargia sp.*	*	*	*
7	Rusty Marsh Dart	*Ceriagrion olivaceum*	*	*	*
8	Common orange	*Ceriagrion sp.*	*	*	*
9	Painted Sprite Damselfly	*Pseudagrion sp.*		*	*
10	Common blue damselfly	*Enallagma sp.*		*	*
11		*Ischnura sp*	*	*	
12		*Agriocnemis sp*		*	
ii	**Family: Lestidae**				
13	Green Emerald	*Lestes virdis*	*		*
14	Emerald spreadwing	*Lestes dryas*		*	*
15	Common spreadwing	*Lestes sponsa*	*		
iii	**Family: Protoneuridae**				
16	Blue Bambootail				*
iv	**Family: Playtcnemididae**				
17	Yellow Bush Dart	*Copera marginipes*	*	*	
B	*Sub-order Anisoptera*				
v	**Family: Aeshnidae**				
18	Hawker Dragonfly	*Aeshna sp.*	*		
vi	**Family: Gomphidae**				
19	Common clubtail	*Ictinogomphus rapax*	*	*	*
20	Snaketail	Ophiogomphus sp.	*	*	*
vii	**Family: Cordulegasteridae**				
21	Spiketail	*Cordulegaster sp*	*		*
viii	**Family: Libellulidae**				
22	Wandering Glider	*Pantala flavescens*	*	*	*
23	Ditch Jewel	*Brachythemis contaminata*	*	*	*
24	Long - legged Marsh Glider	*Trithemis pallidinervis*	*	*	*
25	Ruddy marsh skimmer	*Crocothemis servilia*	*	*	*
26	Common Scarlet Darter	*Crocothemis erythraea*	*	*	*
27	Ground skimmer	*Diplacodes trivialis*	*	*	*
28	Black Percher	*Diplacodes lefebvrii*	*	*	*
29	Black tipped Percher	*Diplacodes nebulosa*			*
30	Pygmy Skimmer	*Tetrathemis platyptera*			*
31	Common Picture Wing	*Rhyothemis variegata*	*	*	*
32	Yellow-tailed Ashy Skimmer	*Potamarcha congener*		*	*
33	Crimson marsh glider	*Trithemis aurora*	*	*	*
34	Orange winged Dropwing	*Trithemis kirbyi*	*	*	*
35	Granite Ghost	*Bradinopyga geminata*	*	*	*
36	Blue Marsh Hawk	*Orthetrum glaucaum*	*	*	
37	Black-tailed Skimmer	*Orthetrum cancellatum*		*	
38	Blue-tailed Forest Hawk	*Orthetrum triangulare*		*	

39	Slender skimmer	*Orthetrum sabina*	*	*	*
40	Black Pennant	*Selysiothemis sp.*	*	*	*
41	Vagrant Darter	*Sympetrum vulgatum*	*	*	*
42	Meadow hawk Dragonfly	*Sympetrum commixtum*	*		*
43		*Sympetrum sp.*	*	*	*
44		*Brachydiplax sp.*	*	*	
45	Demon Dragonfly	*Indothemis sp.*	*	*	
II	**Order: Orthoptera**				
A	*Sub-order: Ensifera*				
i	**Family: Tettigonidae**				
46	Broad-winged katydid	*Microcentrum rhombifolium*			*
47	Long horned grasshopper	*Neoconcocephalus ensiger*			*
48	Ground Grasshopper		*	*	*
ii	**Family: Gryllidae**				
49	Field Cricket	*Gryllus campestris*		*	*
iii	**Family: Gryllotalpidae**				
50	Mole Cricket	*Gryllotalpa africana*			*
B	*Sub-order : Caelifera*				
iv	**Family: Acrididae**				
51	Short horned Grasshopper	*Txyalis turrita*	*	*	*
52	Painted Grasshopper	*Piokilocercus pictus*	*	*	*
III	**Order: Dicytoptera**				
A	**Sub-order: Mantodea**				
i	**Family: Mantidae**				
53	Praying Mantis	*Mantis religosa*	*	*	*
IV	**Order: Isoptera**				
i	**Family: Rhinotermitidae**				
54	Subterranean Termite	*Rhinotermes sp.*	*	*	*
V	**Order: Hemiptera**				
A	*Sub-order : Auchenorrhyncha*				
i	**Family: Membracidae**				
55	Two horned Treehopper	*Oxyrhachis tarandus*	*	*	*
56	One horned Treehopper	*Oxyrhachis sp.1*	*	*	*
57	Small Treehopper	*Oxyrhachis sp. 2*	*	*	*
ii	**Family: Cicadellidae**				
58	Leaf hopper	*Idioscopus nifeosparsus*		*	
iii	**Family: Lophopidae**				
59	Sugarcane Leaf-borer	*Pyrilla perpusilla*	*	*	*
B	*Sub-Order: Sternorrhyncha*				
iv	**Family : Aphididae**				
60	Aphid	*Aphis gossypii*	*	*	*
61	Aphid	*Aphis nerii*	*	*	*
v	**Family: Aleyrodidae**				
62	White fly	*Bemisia tabacci*	*	*	*
vi	**Family: Coccidea**				
63	Scale Insect	*Coccus sp.*	*	*	*
vii	**Family: Pseudococcidae**				
64	Mealy bug	*Phenacoccus sp.*		*	
C	*Sub-order : Heteroptera*				
viii	**Family: Pyrrhocoridae**				
65	Red cotton bug	*Dysdercus cingulatus*	*	*	*

ix	**Family: Pentatomidae**				
66	Green stink bug	*Nezare viridula*	*	*	*
67	Stink bug	*Aspongus janus*		*	*
68	Brown stink bug	*Halymorpha halys*			*
x	**Family: Lygaeidae**				
69	Milkweed bug	*Lygaeus sp*	*	*	*
xi	**Family: Reduviidae**				
70	Assasin bug	*Oncocephalus sp.*			*
xii	**Family: Gerridae**				
71	Water stridder	*Gerris sp.*	*	*	*
xiii	**Family: Belostomidae**				
72	Gaint Waterbug	*Belatoma sp.*			*
xiv	**Family: Nepidae**				
73	Water scorpion	*Nepa sp.*			*
VI	**Order: Coleoptera**				
A.	*Sub-order: Adephaga*				
i	**Family:Carabidae**				
74	Ground Beetle	*Scaritus subterraneus*	*	*	*
75		*Scaritus sp. 1*	*		
76	Six spotted Beetle	*Anthia sexguttata*	*		
B.	*Sub-order: Polyphaga*				
ii	**Family: Dermastidae**				
77	black carpet beetle	*Attagenus sp.*	*	*	*
iii	**Family: Buprestidae**				
78	Metallic green beetle	*Chrysochus sp.*	*		
79	Black tree boring beetle	*Agrilus sp.*	*		
80	Metallic grey beetle				*
iv	**Family: Curculionidae**				
81	Black snout Beetle	*Anthonomous sp.*			*
82	Grey Snout beetle	*Anthonomus sp.1*	*		
83	Orange snout beetle	*Anthonomus sp.2*	*		
84	Long snout beetle	*Aulacobris sp*	*		
85	Yellow Snout beetle with black spots			*	
v	**Family: Coccinellidae**				
86	Lady Bird Beetle	*Cocinella septempunctata*	*	*	*
vi	**Family: Meloidae**				
87	Blister Beetle	*Mylabris sp.*	*	*	*
VII	**Order: Diptera**				
A.	*Sub-order: Brachycera*				
i	**Family: Sarcophagidae**				
88	Flesh fly	*Sarcophaga sp.*	*	*	*
ii	**Family: Tabanidae**				
89		*Chrysops sp*	*	*	
90	Yellow fly	*Diachlorus sp.*		*	
iii	**Family: Drosophilidae**				
91	Fruit fly	*Drosophila sp.*	*	*	
iv	**Family: Calliphoridae**				
92	Blue bottle fly	*Calliphora vomitoria*		*	*
v	**Family: Muscidae**				
93	House fly	*Musca domesticus*	*	*	*
B	*Sub-order:Nematocera*				
vi	**Family: Chironomidae**				

94	Midge	*Chironomous sp.*	*	*	*
vii	**Family: Culicidae**				
95	Mosquito	*Culex sp.*	*	*	*
VIII	**Order: Lepidoptera**				
A.	*Sub-order: Ditrysia*				
A1	*Super family: Papilionoidea*				
i	**Family: Papilionidae**				
96	Common Rose	*Atrophaneura aristolochiae*	*		*
97	Crimson Rose	*Atrophaneura hector*	*		
98	Lime Butterfly	*Papilio demoleus*	*	*	*
99	Common Mormon	*Papilio polytes*			*
100	Tailed Jay	*Graphium agammnon*	*	*	*
ii	**Family: Pieridae**				
101	Plain Sulphur	*Dercas lycorias*	*	*	*
102	Psyche	*Leptosia nina*	*	*	*
103	Common Jezbel	*Delias eucharis*	*	*	*
104	Indian Cabbage White	*Pieris canidia*	*	*	
105	Common Gull	*Cepora nerissa*	*	*	*
106	Pioneer	*Belenois aurota*	*	*	*
107	White Orange tip	*Ixias marianne*	*	*	*
108	Yellow Orange tip	*Ixias pyrene*	*	*	*
109	Great Orange tip	*Hebomoia glaucippe*		*	
110	Common Emigrant	*Catopsilia pomona*	*	*	*
111	Mottled Emigrant	*Catopsilia pyranthe*	*	*	*
112	Common Grass Yellow	*Eurema hecaba*	*	*	*
113	Spotless Grass yellow	*Eurema laeta*		*	*
114	Common Wanderer	*Pareronia valeria*	*	*	*
115	Crimson tip	*Calotis danae*		*	
116	Small Salmon Arab	*Colotis amata*	*	*	*
iii	**Family: Lycaenidae**				
117	Forget-me-not	*Catochrysops strabo*			*
118	Stripped Pierriot	*Tarucus indica*	*	*	*
119	Common pierriot	*Castalius rosimon*		*	*
120	Rounded Pierriot	*Tarucus nara*		*	
121	Indian cupid	*Everes lacturnus*	*	*	*
122	Gram blue	*Euchrysops cnejus*	*	*	*
123	Lesser Grass blue	*Zizina otis*	*	*	*
124	Tiny Grass blue	*Zizina hylax*	*	*	*
125	Grass jewel	*Freyeria trochylus*			*
126	Pea blue	*Lampides boeticus*	*		*
iv	**Family: Nymphalidae**				
127	Plain Tiger	*Danaus chrysippus*	*	*	*
128	Stripped Tiger	*Danaus genutia*	*	*	*
129	Common Crow	*Euploea core*	*	*	*
130	Blue Tiger	*Tirumala limniace*			*
131	Common Evening Brown	*Melanitis leda*			*
132	Common Castor	*Ariadne merione*	*	*	
133	Joker	*Byblia ilithyia*			*
134	Yellow Pansy	*Junonia hierta*	*		
135	Blue pansy	*Junonia orithya*	*	*	*
136	Peacock pancy	*Junonia almana*	*	*	*
137	Lemon pansy	*Junonia lemonias*		*	*
138	Grey Pansy	*Junonia atlites*	*	*	*
139	Chocolate pansy	*Junonia iphita*			*

140	Painted Lady	*Vanessa cardui*	*	*	*
141	Danaid eggfly	*Hypolimnas missipus*	*	*	*
142	Great eggfly	*Hypolimnas bolina*			*
143	Baronet	*Euthalia nais*			*
144	Tawny coster	*Acraea terpsicore*	*	*	*
A2	*Superfamily: Noctuoidea*				
v	**Family: Arctiidae**				
145	Tiger moth	*Utetheisa pulchella*	*	*	*
146	Nine spotted moth	*Syntomis phegea*	*	*	
vi	**Family: Noctuidae**				
147	Castor Semi-looper moth	*Achaea janata*	*	*	*
148	Cotton ball worm	*Helicoverpa armigera*	*	*	*
149	Tobacco cutworm	*Spodoptera litura*	*		*
A3	*Superfamily: Pyraloidea*				
vii	**Family: Pyralidae**				
150	Wax moth	*Galleria sp.*	*		
151		*Achroia sp.*			*
A4	*Superfamily: Bombycoidea*				
viii	**Family: Sphingidae**				
152	Green Hawk Moth	*Pergesa acteus*			*
IX	**Order: Hymenoptera**				
A	*Sub-order: Apocrita*				
A1	*Superfamily: Vespoidea*				
i	**Family: Formicidae**				
153	Small red ant	*Oecophylla smaragdina*	*	*	*
154	Small black ant	*Monomorium minimum*	*	*	*
155	Large black ant	*Componotus compressus*	*	*	*
156		*Componotus radiatus*			*
157	Carpenter Ant	*Componotus sericeus*	*	*	*
158		*Componotus sp.1*	*	*	*
159		*Camponotus sp. 2*		*	
160		*Camponotus sp.3*	*		
161		*Camponotus sp.4*			*
162	Red imported fire ant	*Solenopsis invicta*	*	*	*
163		*Solenopsis sp.1*	*	*	*
164		*Solenopsis sp.2*			*
165		*Solenopsis sp. 3*		*	
166	Arboreal Bicolored Ant	*Tetraponera rufonigra*	*	*	*
167		*Dorylus labiatus*		*	*
168		*Monomorium sp.*			*
169		*Lasius sp.*			*
170		*Tetramorium sp.*	*		
171		*Anoplolepsis sp.*	*		
172		*Leptogenys sp.*	*		
ii	**Family: Vespidae**				
173	Common Wasp	*Ropalidia marginata*	*	*	*
174	Common yellow jacket	*Paravespula vulgaris*		*	*
175	Paper wasp	*Polistes sp.*			*
176		*Dolichovespula sp.*	*	*	
177	Indian Hornet	*Vespa sp.*		*	

178	Potter wasp	*Eumenes sp.*	*	*	*
179		*Mondia quadridens*			*
A2	*Superfamily: Chrysidoidea*				
iii	**Family: Chrysididae**				
180	Cuckoo wasp	*Chrysis sp.*			*
A3	*Superfamily: Apoidea*				
iv	**Family : Sphecidae**				
181	Thread waisted wasp	*Sphex lobatus*	*		
182		*Sphex sp. 1*		*	*
183		*Sphex sp.2*	*	*	
184		*Sphex sp.3*		*	
v	**Family: Xylocopidae**				
185	Carpenter Bee	*Xylocopa aestuans*	*	*	*
vi	**Family: Apidae**				
186	Bumble Bee	*Bombus psthyrus*	*	*	*
187	Honey Bee	*Apis dorsata*	*	*	*
188	Metallic Green Bee	*Agapostemon virescens*		*	*

REFERENCES

Abensperg-Traun, G. T., Smith, G. T., Arnold, G. W. and Steven, D. E. 1996. The effects of habitat fragmentation and livestock grazing on animal communities in remnants of gimlet *Eucalyptus salubris* woodland in the Western Australian wheat belt. I. Arthropods. *J. Appl. Ecol.,* **33**: 1281–1301.

Afton, A. D. and Ankney, C. D. 1991. Nutrient-reserve dynamics of breeding Lesser Scaup: A test of competing hypotheses. *Condor***, 93**:89-97.

Ahmad, I. and Schaefer, C. W. 1987. Food plant and feeding biology of the Pyrrhocoridae (Hemiptera). *Phytophaga*, **1**: 75–92.

Ahmed, A., Suhail, A., Zain –ul-Abdin, Iftikhar, S. and Zahoor, K. 2004. Biodiversity of insects associated with sugarcane crop in Faisalabad. *Pak. Entomol.,* **26**(1) 65-69.

Alatalo, R. V. 1981. Habitat selection of forest birds in the seasonal environment of Finland. *Ann. Zool. Fennici*, **18**: 103-114.

Albrecht, M. and Gotelli, N. J. 2001**.** Spatial and temporal niche partitioning in grassland ants. *Oecologia,* **126:** 134–141.

Aldrich, H. C. 1946. Butterflies of Kaira District- a list. *J. Bombay Nat. His. Soc.,* **46** (2):374-377.

Ali, M. H., Rao, B. H. K., Rao, M. A. and Rao, P. S. 1981. Bird (*Psittacula krameri*) damage to maize. *J. Bombay Nat. His. Soc.*, **79**: 201–204.

Ali, S. 2007. Butterflies of Sharavathi river basin. *Envis Newsletter,* Issue VII Sahyadri: Western Ghats Biodiversity Information System**.**

Ali, S. and Ripley, S. D. 1983. *Handbook of the Birds of India and Pakistan* (Compact Edition). University Press Bombay. Bombay, India.

Alonso, L. E. and Agosti, D. 2000. Biodiversity studies, monitoring, and ants: an overview. In*:* (Eds.) Agosti, D., Majer, J. D., Alonso, L. E. and Schultz, T. R. *Ants: Standard Methods for Measuring and Monitoring Biodiversity*. Smithsonian Institution Press, Washington, DC. Pp.1—8.

Alonso, L. E., Kaspari, M. and Agosti, D. 2000. Ants as indicator of diversity and using ants to monitor environmental change. In: Eds. Agosti, D., Majer J. D. Alonso, L. E., and Schultz, T. R. *Ant: Standard Method for Measuring and Monitoring Biodiversity*, Smithsonian Institution Press, Washington, U.S.A. *pp* 80- 98.

Aluri, J. S. R. and Rao, S. P. 2002. Psychophily and evolution consideration of *Cadaba fructicosa* (Capparaceae). *J. Bombay Nat. His. Soc.,* **99** (1): 59−63.

Andersen, A. N. 1990. The use of ant communities to evaluate change in Australian terrestrial ecosystems: a review and a recipe. *Proc. Eco. Soc. Australia,* **16**: 347-357.

Andersen, A. N. 1991. Responses of ground-foraging ant communities of three experimental fire regimes in a savanna forest of tropical Australia. *Biotropica*, **23**: 575-585.

Andersen, A. N. 1995. A classification of Australian ant communities based on functional groups which parallel plant life-forms in relation to stress and disturbance. *J. Biogeo.,* **22**: 15–29.

Andersen, A. N. 1999. My bioindicator or yours? Making the selection. *J. Insect Conser.,* **3**: 61–64.

Andersen, A. N. and Majer, J. D. 2004. Ants show the way down Under: invertebrates as bioindicators in land management. *Frontiers Eco. Environ.,* **2**:291–298.

Andersen, A. N., and McKaige**,** M. E. 1987. Ant communities at Rotamah Island, Victoria, with particular reference to disturbance and *Rhytidoponera tasmaniensis*. *Proc. Royal Soc.Victoria,* **99**: 141-146.

Andersen, A. N., Fisher, A., Hoffmann, B. D., Read, J. L. and Richards, R. 2004. The use of terrestrial invertebrates for biodiversity monitoring in Australian rangelands with particular reference to ants. *Austral. Ecology,* **29**:87–92.

Anderson, J. M. and Flanagan, P. 1989. Biological processes regulating organic matter dynamics in tropical soils. *In:* Eds. Oades, T., Uheara, G. and Coleman, D. C. *Dynamics of Soil Organic Matter in Tropical Ecosystems.* Honolulu: Niftal Project, University of Hawaii. pp. 97-125.

Anderson, M. D., Anderson, R. A., Anderson, S. L., Anderson, T. A., Bader, U., Heinrich D., Hofmeyer, J., Kolberg, C., Kolberg, H., Komen, L., Paterson, B., Paterson, J., Sinclair, K., Sinclair, W., Van Zijl, D. and Van Zijl, H. 2001. Notes on the birds and other animals recorded at the Cunene River mouth from 6-8 January 2001. *Bird Numbers,* 10(1): 52– 57.

Andrew, N. R. and Hughes, L. 2005. Diversity and assemblage structure of phytophagous Hemiptera along a latitudinal gradient: predicting the potential impacts of climate change. *Global Eco. Biogeo.,* **14** : 249–262.

Anonymous 2006. A preliminary list of butterflies from Jambughoda Wildlife Sanctuary, Gujarat India. Report submitted to Forest Department, Gandhinagar.

Anu A. 2006. *Entomofaunal dynamics and biochemistry of litter decomposition in a natural forest with special reference to the systematic of dung beetles (Coleoptera: Scarabaeinae).* Ph.D Thesis submitted to University of Calicut, Kerala, India.

Anu, A., Sabu, T. K. and Vineesh P. J. 2009. Seasonality of litter insects and relationship with rainfall in a wet evergreen forest in south Western Ghats. *J. Insect Sci.,* **9:**46-55.

Arulprakash, R. and Gunathilagaraj, K. 2010. Abundance and diversity of Odonata in temporary water bodies of Coimbatore and Salem districts in Tamil Nadu. *J. Threat. Taxa*, **2**(8): 1099-1102.

Arun, P. R. 2008. Seasonality of swallowtail butterfly community (Lepidoptera: Papilionidae) of Siruvani forest, Western Ghats, Southern India. Sem. Proc. "*Wonderful world of Insects*" 66-70.

Arun, P. R. and Azeez, P. A. 2003. On the Butterflies of Puyankutty forests, Kerala, India. *Zoo's Print J.*, **18**(12): 1276-1279.

Arun, P. R. and Vijayan, V. S. 2004. Patterns in Abundance and Seasonality of Insects in the Siruvani Forest of Western Ghats, Nilgiri Biosphere Reserve, Southern India. *The Sci. World J.*, **4**: 381–392.

Asahina, S. 1993. *A list of the odonata from Thailand* (Parts I–XXI) (Ed. Pinratana, A.), Sio Yoo Dee: Yannawa, Bangkok.

Asaithambi, M. and Manickavasagam, S. 2002. Odonata of Annamalai University, Annamalainagar, Tamil Nadu, India. *Zoo's Print J.,* **17** (2): 704-706.

Askew, R. R. 1988. *The Dragonflies of Europe.* Harley Books, Martins, Great Horkesley, Colchester, Essex, England, 291 pp.

Asokan, S. 1998. Food and feeding habits of the Small Green Bee-eater *Merops orientalis* in Mayiladuthurai. *J. Ecobio.,* **10**(3): 199-204.

Asokan, S., Ali, A. M. S. and Manikannan, R. 2009. Diet of three insectivorous birds in Nagapattinam District, Tamil Nadu, India – a preliminary study. *J. Threat. Taxa*, ***1***(6): 327-330.

Atkinson, E. C. and Cade, T. J. 1993. Winter foraging and diet composition of Northern Shrikes in Idaho. *The Condor,* **95**:528-535.

Austin, G. T. and Tomoff, C. S. 1978. Relative abundance in bird populations. *Am. Nat.*, **112**: 695-699.

Aynalem, S. and Bekele, A. 2008. Species Composition, relative abundance and distribution of bird fauna of riverine and wetland habitats of Infranz and Yiganda at southern tip of Lake Tana Ethopia. *Tropical Ecol.*, **49**(2): 199-209.

Azrina, M. Z., Yap, C. K., Ismail, A. R., Ismail, A. and Tan, S. G. 2006. Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River Peninsular Malaysia. *Ecotoxi. Environ. Safety*, **64**: 337-347.

Baker, H. G. and Baker, I. 1982. Chemical constituents of nectar in relation to pollination mechanisms and phylogeny. *In:* (ed.) Nitecki, M. *Biochemical aspects of evolutionary biology*. Univ. of Chicago Press, Chicago. Pp.131-171.

Balfour, R. P. 2007. *The Impact of Changes in Average Winter Temperatures and Habitat Modification on Populations of Terrestrial Birds Over-wintering in Inland Areas of Massachusetts.* M. Sc. Thesis submitted to the Field of Natural Sciences, Harvard University USA.

Balmer, O. and Erhardt, A. 2000. Consequences of Succession on Extensively Grazed Grasslands for Central European Butterfly Communities: Rethinking Conservation Practices. *Conser. Bio.,* **14**(3): 746–757.

Barlow, H. S. and Woiwod, I. P 1989. Moth diversity of a tropical forest in peninsular Malaysia. *J. Tropical Eco.,* **5**:37-50.

Barua, K. K., Slowik, J., Bobo, K. S. and Muehlenberg, M. 2010. Correlations of Rainfall and Forest type with Papilionid assemblages in Assam in Northeast India. *Psyche,* Article ID 560396, 10

Basset, Y. 1991. The seasonality of arboreal arthropods foraging within an Australian rainforest tree. *Ecol. Entomol.,* **16**: 265-278.

Basset, Y., Novotny, V., Miller, S. E. and Springate, N. D. 1998. Assessing the impact of forest disturbance on tropical invertebrates: some comments. *J. Appl. Ecol.,* **35**: 461–466.

Batzer, D. P. and Wissinger, S. A. 1996. Ecology of insect communities in non-tidal wetlands. *Ann, Rev. Entomol.,* **41**: 75-100.

Baumann, R. W. 1979. Nearctic stonefly genera as indicators of ecological parameters (Plecoptera: Insects). *Great Basin Nat.,* **39**:241-244.

Bawa, K. S. 1990. Plant-pollinator interactions in tropical rain forests. *Ann. Rev. Eco. Evo. Sys.,* **21**:399–422.

Begon, M, Harper, J. L, Townsend, C. R. 1996. *Ecology: Individuals, populations and communities*. Blackwell Science Ltd. UK.

Bengtsson, J., Jones, H. and Setela, H. 1997. The value of biodiversity. *Trends in Ecol. Evo.,* **12**: 334-335.

Bergey, E. A., Balling, S. F., Collins, J. N., Lamberti, G. A. and Resh, V. H. 1993. Bionomics of invertebrates within an extensive *Potamogeton pectinatus* bed of a California marsh. *Hydrobio.,* **234**: 15-24.

Bernstein, R. A. 1979. Schedules of foraging activity in species of ants. *J. Animal Eco.,* **48:** 921–930.

Bestelmeyer, B. T., Ward, J. P. and Havstad, K. M. 2006. Soil-geomorphic heterogeneity governs patchy vegetation dynamics at an arid ecotone. *Ecology,* **87**: 963–973.

Bethke, R. W. and Nudds, T. 1993. Variation in the diversity of ducks along a gradient of environmental variability. *Oecologia,* **93**: 242-250.

Beukema J. J. 2007. Are observed dispersal capacities in Damselfly species sufficient to cope with the ongoing rapid shift of climate zones? In: Tyagi, B. K. (Ed.) *Odonata: Biology of Dragonflies.* Scientific Publishers, India. pp175-182.

Bhalodia K., Bhuva, V. J., Dave, S. M. and Soni, V. C. 2002. Butterflies of Ratanmahal Wildlife Santuary, Gujarat. *Zoos' Print J.,* **17**(10):905-906.

Bharti, H. 2008. Altitudinal Diversity of ants in Himalayan regions (Hymenoptera: Formicidae). December 2007. http://ces.iisc.ernet.in/thresi/AntsOfIndia.html,

Bharti, H. and Alpert, G. D. 2007. *Ants of India*. Downloaded from www.antdiversity.com/ 26.

Bharti, H. and Sharma, Y. P. 2009. Diversity and Abundance of ants along an elevational gradient in Jammu- Kashmir Himalaya – I. *Halteres*, **1**(1): 10-24.

Bibby, C., Burgess, N. D., and Hill, D. A. 1992. *Bird Census Techniques***.** Academic Press, Cambridge.

Bisby, F. A. 1995. Characterization of biodiversity. *In:* Ed. Heywood, H. *Global Biodiversity Assessment*, Cambridge University Press, Cambridge, UK. pp. 21–106.

Blair, R. B. 1999. Birds and butterflies along an urban gradient: surrogate taxa for assessing biodiversity? *Ecol. Appl.,* **9**:164-170.

Boggs C. L., Watt, W. B. and Ehrlich, P. R. 2003. *Butterflies: Ecology and Evolution Taking Flight*, 1st edn. University of Chicago Press, Chicago.

Boinski, S. and Fowler, N. L. 1989. Seasonal patterns in a tropical lowland forest. *Biotropica,* **21:** 223–233.

Bolduc, F. and Afton, A. D. 2004. Hydrologic aspects of marsh ponds during winter on the Gulf Coast Chenier Plain, USA: effects of structural marsh management. *Marine Ecol. Progress Series,* **266**:35-42.

Boppre, M., Robert, L., Schneider, D. and Meinwald, J. 1978. Behaviorally Mediated Contacts Between Scent Organs: Another Prerequisite for Pheromone Production in *Danaus chrysippus* Males (Lepidoptera). *J. Compar. Physiol.,* **126**: 97-103.

Borges, R. M., Gowda, V. and Zacharias, M. 2003. Butterfly pollination and high contrast visual signals in a low-density distylous plant. *Oecologia,* **136:** 571-573.

Boucher, D. H., James, S. and Keeler, K. H. 1982. The ecology of mutualism. *An. Rev. Eco. Sys.,* **13**: 315-347.

Boutin, S. 1990. Food supplementation experiments with terrestrial vertebrates: patterns, problems, and the future. *Can. J. Zoo.,* **68**: 203-220.

Braithwaite, R. W. 1991. Australia's unique biota: Implications for ecological processes. In: Ed. Werner, P. A. *Savanna Ecology and Management: Australian Perspectives and Intercontinental Comparisons.* Blackwell Scientific Publications, Oxford, pp. 3–10.

Breymeier, A. 1971. Productivity investigation of two types of meadows in the Vistula valley. *Ekologia Polska,* **19:** 93-201.

Brian, M. V. 1978. *Production Ecology of Ants and Termites*. IBP 13, Cambridge University Press, Cambridge, U K.

Bried, J. T. 2005. *Community and Conservation Ecology of Dragonfly and Damselfly adults in Mississippi Wetlands.* M. Sc. Thesis Submitted to the Faculty of Mississippi State University, Mississippi State, Mississippi.

Bried, J. T. and Ervin, G. N. 2005. Distribution of Adult Odonata among Localized Wetlands in East- central Mississippi. *Southeastern Naturalist,* **4**(4): 731-744.

Bried, J. T. and Ervin, G.N. 2006. Abundance patterns of dragonflies along a wetland buffer. *Wetlands,* **26**(3): 878-883.

Bried, J. T., Herman, B. D. and Ervin, G. N. 2007. Umbrella potential of plants and dragonflies for wetland conservation: a quantitative case study using the umbrella index. *J. Appl. Eco.,* **44:** 833–842.

Briers, R. A. and Biggs, J. 2003. Indicator taxa for the conservation of pond invertebrate diversity. *Aqu. Conser.: Marine and Freshwater Ecosys.,* **13**: 323-330.

Bristow, C. M. 1983. Treehoppers transfer parental care to ants: a new benefit of mutualism. *Science*, **220**: 532-533.

Bristow, C. M. 1991. Are ant-aphid associations a tritrophic interaction? Oleander aphids and Argentine ants. *Oecologia* (Berl.), **87**: 514-521.

Bromham, L., Cardillo, M., Bennett, A. F. and Elgar, M. A. 1999. Effects of stock grazing on the ground invertebrates fauna of woodland remnants. *Aus. J. Ecol*., **24**: 199-207.

Brown, A. and Collier, N. 2004. *Terrestrial Birds of the Katouche Valley, Anguilla.* The Results of Environmental Protection. In the Caribbean's Research During the Winter of 2004. A Report to the Anguilla Ministry of the Environment, Anguilla.

Brühl, C. A., Gusalam, G. and Linsenmair, K. E. 1998. Stratification of ants in a rain forest of Borneo. *J. Tropical Eco.,* **14**: 285-297.

Brühl, C. A., Mohamed, M. and Linsenmair, K. E. 1999. Altitudinal distribution of leaf litter ant along a transect in primary forest on mount Kinabalu, Sabah, Malaysia. *J. Trop. Ecol.,* **16**: 265-267.

Bucher. E. H. 1982. Chaco and Caatinga-South American Arid Savannas, Woodlands and Thickets. *In:* Eds. Huntley, B. J. and Walker, B. H. *Ecology of Tropical Savannas*, Springer-Verlag Berlin, pp. 48-79.

Buckley, R. C. 1987. Interactions involving plants, Homoptera, and ants. *An. Rev. Eco. Sys.,* **18**: 111-135.

Burgmer, T., Hillebrand, H. and Pfenninger, M. 2007. Effects of climate-driven temperature change on the diversity of freshwater macroinvertebrates. *Oecologia*, **151**: 93-103.

Cahoon, D. R. and Stevenson, J. C. 1986. Production, predation and decomposition in a low salinity *Hibiscus* marsh. *Ecology,* **67**: 1341-1350.

Cameron, S. A., Hines, H. M. and Williams, P. H. 2007. A comprehensive phylogeny of the bumble bees (*Bombus*). *Biol. J. Linn. Soc*., **91:** 161–188.

Cannings, R. A., Ramsay, L. R. and Cannings, S. G. 2007. Odonata Inventories in British Columbia, Canada: determining the Conservation Status of Odonata Species. In: Tyagi, B.K. (Ed.) *Odonata: Biology of Dragonflies*. Scientific Publishers, India. Pp 137-151.

Carchini, G., Solimni, A. G. and Ruggiero, A. 2005. Habitat characteristics and odonate diversity in mountain ponds of central Italy. *Aqu. Conser.: Marine and Freshwater Ecosys.*, **15**: 573-581.

Carle, F. L. 1979. Enviromental monitoring potential of Odonata, with a list of rare and endangered Anisoptera of Virginia, United states. *Odonatologica*, **8**:319-323.

Carpenter, S. R., Kitchell, J. F., Fisher, S. G. and Grimm, N. B. 1992. Global change and freshwater ecosystems. *Ann. Rev. Eco. Syst.*, **23**: 119-139.

Caughley, G. 1982. *Analysis of vertebrate populations*. John Wiley, New York.

Ceballos, G. and Ehrlich, P. R. 2006. Global mammal distributions, biodiversity hotspots, and conservation. *Proc. Nat. Aca. Sci*., **103:**19374– 19379.

Cervancia, C. R. 2003. Utilization of non-*Apis* species for pollination. *J. Palynology*, **39:** 23–25.

Chadab, R. 1979. *Army ant predation on social wasps*. Ph. D. Dissertation. University of Connecticut-Storrs, Connecticut.

Chakravarthy, A. K. 1988. Bird predation of poel borere of field bean (Lablab Niger Medick). *Tropical Pest Management*, **34**:395-398.

Chakaravarthy, A. K., Rajagopal, D. and Jagannatha, R. 1997. Insects as bio indicators of conservation in the tropics. *Zoo's Print J.,* **12**: 21-25.

Chandrashekara, K., Bhagavan, S., Chandran, S., Nair, P., and Gadagkar, R. 1990. Perennial indeterminate colony cycle in a primitively eusocial wasp. *In*: Eds. Veeresh, G. K., Mallik, B. and Viraktamath, C. A. *Social Insects and the Environment*. Proceedings of the 11th International Congress of IUSSI, Bangalore, New Delhi: Oxford & IBH Publ. Co. pp. 81.

Chavhan, A. and Pawar, S. S. 2011. Distribution and Diversity of Ant Species (Hymenoptera: Formicidae) in and Around Amravati City of Maharashtra, India. *World J. Zoo.,* **6** (4): 395-400.

Chelmick, D., Hammond, C., Moore, N. and Stubbs, A. 1980. *The conservation of dragonflies*. Nature Conservancy Council, Interpretive Branch, London.

Chovanec, A. 1994. Libellen als Bioindikatoren. *Anax*, 1-9.

Chovanec, A. and Waringer, J. 2001. Ecological integrity of river-floodplain systems-assessment by dragonfly surveys (Insecta: Odonata). *Reg. River-Res. Manag.*, **17** (4-5): 493-507.

Chovanec, A., Waringer, J., Raab, R. and Laister, G. 2004. Lateral connectivity of a fragmented large river system: assessment on a macroscale by dragonfly surveys (Insecta: Odonata). *Aqu. Conser*., **14** (2): 163-178.

Clark, F. 1992. A study of a population of *Micronecta scutellaris* Stal (Hemiptera; Corixidae) in Lake Naivasha, Kenya. *Hydrobiologia*, **248**(2): 115-114.

Clark, T. E. and Samways, M. J. 1994. An inventory of the damselflies and dragonflies (Odonata of the Kruger National Park, with three new South Africa records. *Af. Entomol.*, **2**: 61–64.

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

Clausnitzer, V. 2003. Dragonfly communities in coastal habitats of Kenya: indication of biotope quality and the need of conservation measures. *Biodiv. Conser.*, **12**: 333-356.

Clausnitzer, V. 2004. Guardians of the watershed. Global status of dragonflies: critical species, threat and conservation: Critical species of Odonata in eastern Africa. *Int. J. Odonatology,* **7** (2): 189-206.

Clausnitzer, V. 2005. *Diplacodes lefebvrii*. IUCN Red List of Threatened Species.

Clausnitzer, V. 2006. Dragonflies (Odonata) of Rufiji District, Tanzania with new records for Tanzania. *J. East Afr. Nat. His.,* **95**(2)**:**139–162.

Clausnitzer, V. 2006. "*Ischnura senegalensis*". IUCN Red List of Threatened Species.

Clausnitzer, V. and Jodicke, R. (Eds.), 2004. Guardians of the watershed global status of dragonflies: critical species, threat and conservation. *Int. J. Odonatology,* **7**: 111–430.

Clausnitzer ,V., Kalkman, V. J., Ram, M., Collen, B., Baillie, J. E. M., Bedjanicˇ, M., Darwall, W. R. T., Dijkstra, K. D. B., Dow, R., Hawking, J., Karube, H., Malikova, E., Paulson, D., Schutte, K., Suhling, F., Villanueva, R. J., von Ellenrieder, N. and Wilson, K. 2009. Odonata enter the biodiversity crisis debate: The first global assessment of an insect group. *Bio.Conser.*, **142**:1864–1869.

Cody, M. L. 1981. Habitat selection in birds: the roles of vegetation structure, competitors, and productivity. *Bioscience,* **31**:107-113.

Collinge, S. K., Prudic, K. K. and Oliver, J. C. 2003. Effects of local habitat characteristics and landscape context on grassland butterfly diversity. *Conser. Bio.*, **17**(1): 178-187.

Connor, E. F., Courtney, A. C. and Yoder, J. M. 2000. Individuals-area relationships: the relationship between animal population density and area. *Ecology,* **81**:734–748.

Cooper, R. J. and Whitmore, R. C. 1990. Arthropod sampling methods in ornithology. *Studies in Avi. Biol.,* **13**:29–37.

Corbet, P. S. 1957. The life-history of emperor dragonfly *Anax imperator Leech* (Odonata: Aeshnidae). *J. Animal Eco.*, **26**: 1-69.

Corbet, P. S. 1962. *A biology of Dragonflies*. Witherby, London.

Corbet, P. S. 1993. Are Odonata useful as bioindicators? *Libellula*, **12**: 91–102.

Corbet, P. S. 1999. *Dragonflies: behaviour and ecology of Odonata*. Cornell University Press, Ithaca, New York and Harley Books, Colchester UK. 829pp.

Corlett R. T. 2004. Flower visitors and pollination in the Oriental (Indomalayan) Region. *Bio. Rev.*, **79**: 497–532.

Corti, D., Kohler S. L. and Sparks, R. E. 1997. Effects of hydroperiod and predation on a Mississippi River floodplain invertebrate community. *Oecologia,* **109** (1): 154-165.

Cox, C. B. and Moore, P. D. 1993. *Biogeography: an ecological and evolutionary approach.* 5th edn, Blackwell Scientific Publications, Oxford, p. 192.

Crocroft, R. B. 2003. The Social Environment of an Aggregating, Ant-Attended Treehopper (Hemiptera: Membracidae: *Vanduzea arquata*). *J. Ins. Behav.,* **16**(1): 79-95.

Crowley, P. H, Nisbet, R. M., Gurney, W. S. C. and Lawton, J. H. 1987. Population regulation in animals with complex life-histories: Formulation and analysis of a damselfly model. *Adv. Eco. Res.*, **17**: 1-54.

Cucco, M. Bryant, D. M. and Malacarna, G. 1993. Differences in diet of common (*Apus apus*) and Pallid (*A. pallidus*) Swifts. *Avocetta,* **17**:131 -138.

Culin, J. D. 1997. Relationship of Butterfly visitation with nectar qualities and flower color in Butterfly Bush, *Buddleia davidii*. *News Lepido. Soc.*, **39**: 35–39.

Czerwinski, Z., Jakubczyk, H. and Petal, J. 1969. The influence of ants of the genus *Myrmica* on the physico-chemical and microbiological properties of soil within the compass of ant hills in Strzeleckie Meadows. *Polish J. Soil Sci.,* **3**: 51-58.

D'Amico, F., Darblade, S., Avignon, S., Blanc-Manel, S. and Ormerod, S. J. 2004. Odonates as Indicators of Shallow Lake Restoration by Liming: Comparing Adult and Larval Responses. *Restor. Ecol.,* **12**(3): 439-446.

Da Silva, R. R. and Silvestre, R. 2004. "Riqueza da fauna de formigas (Hymenoptera: Formicidae) que habita as camadas superficiais do solo em Seara, Santa Catarina," *Papeis Avulsos de Zoologia*, **44**: 1–11.

Dana, N. R. and Ross, M. S. 2004. Appendix 14. Butterflies and Moths of Jackson-Frazier Wetland: Preliminary Inventory Results From 2003-2004 Surveys. A report submitted to Jackson-Frazier Wetland Advisory Committee. 181-185.

Daniels, R. J. R. 1991. Ants as biological indicators of environmental changes. *Blackbuck,* **7**: 51-56.

Danks, H. V. 2006. Key themes in the study of seasonal adaptations in insects. II. Life-cycle patterns. *Jap. J. Appl. Entomol. Zool.,* **41**: 11-13.

Darlington, P. J. 1971. The carabid beetles of New Guinea. Part IV. General considerations; analysis and history of fauna. *Taxonomic supplement*. *Bull. Museum Compar. Zoo.,* **142**: 129-337.

Das, B. P. and Gupta, V. K. 1983. A catalogue of the families Stenogastridae and Vespidae from the Indian sub-region (Hymenoptera: Vespoidea). *Oriental Insects,* **17**:395–464.

Das, K. and Gupta, S. 2010. Aquatic Hemiptera Community of Agricultural Fields and Rain Pools in Cachar District, Assam, North East India. *Assam Uni. J. Sci. Tech.: Bio. Environ. Sci.*, **5**(1): 123-128.

Daubenmire, R. F. 1974. *Plants and Environment.* John Wiley & Sons, Sydney.

David, P. 2011. Discovering Fruit Birds. *Hornbill*, **3**: 16-21.

Davidson, D. W. and Epstein, W. W. 1989. Epiphytic associations with ants. *In: Phylogeny and ecophysiology of epiphytes* (Ed. U. Luttge) pp. 200-233. Springer-Verlag, New York.

Davis, J. A., Rolls, S. W. and Balla, S. A. 1987. The role of the Odonata and aquatic Coleoptera as indicators of environmental quality in wetlands. In: Ed. Mayer, J. D. The *Role of Invertebrates in Conservation and Biological Survey*, Western Australian Department of Conservation and Land Management: Australia; pp 31–42.

Dawkins, R. and Krebs, J. R. 1979. Arms races between and within species. *Proc. Royal Soc. London., B.* **205**: 489-511.

De Clerck-Floate, R. and Cárcamo, H. 2011. Biocontrol Arthropods: New Denizens of Canada's Grassland Agroecosystems. In: Ed. Floate, K. D. Arthropods of Canadian Grasslands (Volume 2): Inhabitants of a Changing Landscape. Biological Survey of Canada, Canada USA. pp. 291-321.

De Graff, J., Schoeman, A. S. and Brandenburg, R. L. 2004. Seasonal development of *Gryllotalpa africana* (Orthoptera: Gryllotalpidae) on Turfgrass in South Africa. *Florida Entomol.,* **87**(2): 130-135.

Deka, T. N., Sudharshan, M. R. and Saju K. A. 2011. New record of bumble bee, *Bombus breviceps* Smith as a pollinator of large cardamom. *Current Science*, **100**(6): 926-928.

Delabie, J. H. C., Agosti, D. and Nascimento, I. C. 2000. Litter ant communities of the Brazilian Atlantic rain forest region. *Curtin Uni. School Environ. Bio. Bull.*, **18**: 1–17.

Del-Carlo, K. and Oliveira, P. S. 1993. Ant-Homoptera interaction: do alternative sugar sources distract tending ants? *Oikos*, **68**:202-206.

Del-Claro, K. and Oliveira, P. S. 1999. Ant-Homoptera Interactions in a Neotropical Savanna: The Honeydew-Producing Treehopper, *Guayaquila xiphias* (Membracidae), and its Associated Ant Fauna on *Didymopanax vinosum* (Araliaceae). *Biotropica*, **31**(1): 135-144.

Denlinger, D. L. 1986. Dormancy in tropical insects. *Ann. Rev. Entomol.*, **31**: 239-244.

Desai, M. and Shanbhag, A. 2007. Birds breeding in unmanaged Monoculture plantations in Goa, India. *Indian Forester*, **133**: 1367-1372.

Deshkar, S. L. 2008. *Avifaunal diversity and Ecology of wetlands in semi-arid zone of Central Gujarat with reference to their conservation and categorization*. Ph.D. Thesis submitted to The M. S. University of Baroda. Vadodara, India.

Deslippe, R. J. and Savolainen, R. 1994. Role of food supply in structuring a population of *Formica* ants. *J. Animal Eco.*, **63**:759-764.

Deutsch, C. A., Tewksbury, J. J., Huey, R. B., Sheldon, K. S., Ghalambor, C. K., Haak, D. C. and Martin, P. R. 2008. Impacts of climate warming on terrestrial ectotherms across latitude. *Proc of Nat Acad. Sci.*, USA, **105**: 66 - 68.

DeVries, P. J. 1987. *The butterflies of Costa Rica and their natural history: Papillionidae, Pieridae, Nymphalidae*. New York, Princeton University, 327 p.

Devy, M. S. and Davidar, P. 2001. Effects of selective felling on the butterflies assemblage in wet forest of Kalakad-Mudanthurai Tiger reserve: conservation implications: conservation implications. Spl. issue on *Current Science*, **80**: 400-405.

Dhandhukia, S. N., Patel, K. B. and Patel, P. K. 2011. Population Estimation of Myna In Gandhinagar, Gujarat. *Life Sci. Leaflets*, **21**:966 – 973.

Dhindsa, M. S. and Saini, H. K. 1994. Agricultural ornithology: an Indian perspective. *J. Biosci.*, **19**: 391-402.

Diamond, J. and Case, T.J. (Eds.) 1986. *Community Ecology*. Harper & Row, New York.

Diaz, M. 1991. Spatial patterns of granivores and nest abundance and nest site selection in agricultural landscapes of Central Spain. *Ins. Soc.*, **38**: 351-363.

Dingle, H. and Khamala, P. M. 1972. Seasonal Changes in Insect Abundance and Biomass in an East African Grassland with reference to Breeding and Migration in Birds. *Ardea*, **59**:216-221.

Domsic, K. 2009. *Odonata as Indicators of Wetland Restoration*. A report presented for 4th year Senior Honours Project and Posters. Environment and Resource studies, University of Waterloo.

Donald, P. F., Green, R. E., and Heath, M. F. 2001. Agricultural Intensification and the collapse of Europe's Farmland Bird Populations. *Proc. Royal Soc.*, **B268**(1462), 25-29.

Dowd, P. F. and Nelsen, T. C. 1994. Seasonal Variation of Sap Beetle (Coleoptera: Nitidulidae) Populations in Central Illinois Cornfield-Oak Woodland Habitat and Potential Influence of Weather Patterns. *Environ. Entomol.*, **23** (5): 1215-1224.

Driver, D., Brewer, R. N., and Cottier, G. J. 1976. Pesticide residues in eggs and chicks from laying hens fed low levels of chlorinated hydrocarbon pesticides. *Poult. Sci.*, **55**: 1544-1549.

Dudley, R. and Adler, G. H. 1996. Biogeography of milkweed butterflies (Nymphalidae: Danainae) and mimetic patterns on tropical pacific archipelagos. *Bio. J. Linnean Soc.*, **57**: 317-326.

Duelli, P. and Obrist, M. K. 1998. In search of the best correlates for local organismal biodiversity in cultivated areas. *Biodiv. Conser.*, **7**: 297–309.

Dunn, R. R. 2005. Modern insect extinctions, the neglected majority. *Conser. Bio.*, **19**: 1030–1036.

Dunn, R. R., Parker, C. R. and Sanders, N. J. 2007. Temporal patterns of diversity: assessing the biotic and abiotic controls on ant assemblages**.** *Bio. J. Linnean Soc.*, **91:** 191–201.

Dvořák, L., **Belicek, J. and Fric, Z. 2009.** Observations of overwintering nymphalid butterflies in underground shelters in SW and W Bohemia (Czech Republic) (Lepidoptera: Nymphalidae: Nymphalini). *J. Res .Lep.*, **41**: 45-52.

Dyer, F. C. and Seeley, T. D. 1994. Colony migration in the tropical honeybee *Apis dorsata* F. (Hymenoptera: Apidae). *Insectes Sociaux,* **41**:129-140.

Ebert, T. A. and Balko, M. L. 1987. Seasonal changes in the invertebrate community of small shallow ephemeral pans at Bain's Vlei, South Africa. *Hydrobiologia,* **317** (1): 51-64

Ekkens, D. 1972. Peruvian treehopper behaviour (Homeptera: Membracidae). *Entomol. News.,* **83**: 257-271.

Elton, C. 1933. *The ecology of animals*. Methuen, London, United Kingdom. 97 p.

Eltz, T., Brühl, C. A., Van der Kaars, S. and Linsenmair, E. K. 2002. Determinants of stingless bee nest density in lowland dipterocarp forests of Sabah, Malaysia. *Oecologia,* **131**: 27-34.

Emiliyamma, K. G. 2005. On the Odonata (Insecta) fauna of Kotayam district, Kerala, India. *Zoo's Print J.*, **20**(12):2108-2110.

Emiliyamma, K. G., Radhakrishnan, C. and Muhamed, J. P. 2005. *Pictorial Handbook on-Common Dragonflies and Damselflies of Kerala*. 67pp. Published: Director, Zoological Survey of India, India, Kolkatta.

Emlen, J. M. 1966. The role of time and energy in food preference. *Am. Nat.*, **100**:611-617.

Erhardt, A. 1985. Diurnal lepidoptera: sensitive indicators of cultivated and abandoned grassland. *J. App. Ecol.,* **22:**849–861.

Erhardht, A. and Thomas, J. A. 1991. Lepidoptera as indicators of change in the semi natural grasslands of lowland and upland Europe. *In*: Eds. Collins, N. M. and Thomas, J. A. *The Conservation of insects and their habitats*. Academic press, London. Pp 213-236.

Erwin, T. L. 1982. Tropical forests: Their richness in Coleoptera and other arthropod species. *Coleopterists Bul.,* **36**: 74–75.

Erwin. T. L. 1983. Beetles and other insects of tropical forest canopies at Manaus, Brazil. sampled by insecticidal fogging. In: Eds. Sutton,S. L., Whitrnore, T. C. and Chadwick, A. C. *Tropical Rainforest: Ecology and Management*. Blackwell Scientific, Oxford. pp. 59-75.

Farji-Brener, A. G. and Ruggiero, A. 1994. Leaf-cutting ants (*Atta and Acromyrmex*) inhabiting Argentina: patterns in species richness and geographical range sizes. *J. Biogeo.,* **21**: 391-399.

Farji-Brener, A. G. and Margutti, L. 1997. Patterns of plant species in relation to Acromyrmex lobicornis nest-mounds on roadside vegetation in Northwest Patagonia. *Int. J. Eco. Environ. Sci.*, **23**:37- 47.

Fauvel, G. 1999. Diversity of Heteroptera in agroecosystems: role of sustainability and bioindication. *Agri. Ecosys. Environ.*, **74:** 275–303.

Feeny, P. 1970. Seasonal changes in oak leaf tannins and nutrients as a cause of spring feeding by winter moth caterpillars. *Ecology,* **51**: 565–581.

Fellers, J. H. 1989. Daily and seasonal activity in woodland ants. *Oecologia,* **78:** 69–76.

Fermon, H., Schulze, C. H., Waltert, M. and Muhlenberg, M. 2001. The butterfly fauna of the Noyau Central, Lama Forest (Republic of Benin), with notes on its ecological composition and geographic distribution. *Afr. Entomol.,* **9**(2): 1-9.

Feuchtmayr, H. D., McKee, D., Harvey, I. F., Atkinson, D. and Moss, B. 2007. Response of macro invertebrates to warming, nutrient addition and predation in large-scale mesocosm tanks. *Hydrobiologia*, **584**: 425-432.

Fjeldså, J., Ehrlich, D., Lambin, E. and Prins, E. 1997. Are biodiversity "hotspots" correlated with current ecoclimatic stability? A pilot study using the NOAA-AVHRR remote sensing data. *Biodiv. Conser.*, **6**: 401–422.

Flenner, I. and Sahlén, G. 2008. Dragonfly community re-organisation in boreal forest lakes: rapid species turnover driven by climate change? *Conser. Div.*, **1**: 169–179.

Folgarait P. J. 1998. Ant biodiversity and its relationship to ecosystem functioning: a review. *Biodiv. Conser.*, **7**:1221-1244.

Folgarait, P. J., Gorosito, N, BenõÂtez, C, FernaÂndez, J. and Pizzio, R. 1996. La ecologõÂa de *Camponotus punctulatus* en relacioÂ n a campos con distintas historias de uso. Simposio de Controle BioloÂ gico. 9±14 June, Foz de IguacËuÂ , Brazil. p. 348.

Folgarait, P. J., Gorosito, N. and Zipeto, G. 1997. Reduction of biodiversity by *Camponotus punctulatus* ants mediated by human *disturbance. Association for Tropical Biology Annual Meeting. Symposium on Tropical diversity, origins, maintenance and conservation*. San Jose, Costa Rica. p. 57.

Foote, A. L., Kadlec, J. A. and Campbell, B. K. 1988**.** Insect herbivory on an inland brackish wetland. *Wetlands,* **8**:67-74.

Forshaw, J. M., 1989. *Parrots of the World*. Blandford, London, England.

Fowler, H. G. and Claver, S. 1991. Leaf-cutter ant assemblies: effects of latitude, vegetation, and behaviour. *In*: Eds. Huxley C. R. and Cutler D. F. *Ant-plant interactions*, New York, Oxford University Press, Pp. 51-59.

Fraser, F. C. 1933-1936. *Fauna of British India including Ceylon and Burma: Odonata*, Vol 1-3. Taylor and Francis, London.

Freeman, P. 1947. A revision of the genus *Dysdercus boisduval* (Hemiptera, Pyrrhocoridae), excluding the American species. *Trans. Royal Entomol. Soc. London*, **98**: 373–424.

Frith, D. and Frith, C. 1990. Seasonality of litter invertebrate populations in an Australian upland tropical rain forest. *Biotropica*, **22**(2): 181-190.

Fritz, R. S. 1982. An ant-treehopper mutualism: Effects of *Formica subsericea* on the survival of *Vanduzea arquata. Eco. Entomol.,* **7:** 267–276.

Fritz, R. S. 1983. Ant protection of a host plant's defoliator: Consequence of an ant-membracid mutualism. *Ecology*, **64:** 789–797.

Fry, C. H. 1984. *The bee-eaters.* T. and A. D. Poyser, Carlton, UK.

Fuisz T. I. and Yosef, R. 1998. Habitat choice of post-breeding Red-backed Shrikes (*Lanius collurio*) in northeastern Hungary. *IBCE Tech. Publ.,* **7**: 26 - 29.

Fuller, R. J., Gough, S. J. and Marchant, J. H. 1995. Bird populations in new lowland woods: landscape, design and management perspectives. In: Ferris-Kaan, R. (Ed.) *The Ecology of Woodland Creation,* Wiley, Chichester, UK. Pp. 163-182.

Funkhouser, W. D. 1915. Life history of *Vanduzea arquata* Say (Membracidae). *Psyche,* **22:**183–199.

Funkhouser, W. D. 1917. Biology of the Membracidae of the Cayuga Lake basin. *Mem. Cornell Univ. Agr. Exp. Stat.,* **2:** 177–445.

Gadagkar, R., Nair, P., Chandrashekhar K. and Bhat, D. M. 1993. Ant species richness in some selected localities in Western Ghats, India. *Hexapoda*, **5**: 70-94.

Gadgakar, R., Gadgil, M., Joshi, N. V., and Mahabal, A. S. 1982. Observations of population ecology and sociobiology of the paper wasp *Ropalidia marginata marginata* (Lep.) (Family Vespidae). *Proc. Indian Acad. Sci. (Anim. Sci.),* **91**:539–552.

Galle, L. 1972. Study of ant-population in various grassland ecosystems. *Acta biologica,* **18:** 159-164.

Galushin V. M. 1971. A huge urban population of birds of prey in Delhi, India. *Ibis,* **113**: 552.

Gaonkar, H. 1996. *Butterflies of the Western ghats, India, including Sri Lanka: Biodiversity assessment of a threatened mountain system*, Centre for Ecological Sciences, Indian Institute of Science, Bangalore and the Natural History Museum, London.

Gaston, A. J. 1975. Methods for estimating bird populations. *J. Bombay Nat. His. Soc.,* **72**: 271-283.

Gaston, K. J. 1996. Species richness: measure and measurement. I*n:* Ed. Gaston K.J. *Biodiversity: a biology of numbers and difference.* Blackwell Science, Cambridge, UK. Pp. 77–113

Gaston, K. J. and Blackburn, T. M. 2000. *Pattern and Process in Macroecology*. Blackwell Science, Oxford.

Gaston, K. J., Blackburn, T. M. and Gregory, R. D. 1999. Does variation in census area confound density comparisons? *J. Appl. Ecol*., 36:191–204.

Gay, T., Kehmikar, I. and Punetha, J. C. 1992. *Common butterflies of India*. WWF India –Oxford University Press, Bombay.

Gess, F. and Gess, S. 1991. Effects of increasing land utilization on species representation and diversity of aculeate wasps and bees in the semi-arid areas of Southern Africa. *In*: Eds. Lasalle, J. and Gauld, I. D. *Hymenoptera and Biodiversity*, CAB International, Pp. 83-113.

Ghadirian, T., Qashqaei, A. Y. and Dadras, M. 2007. Notes on feeding and Breeding Habits of Purple Sunbird Nectarinia asiatica (*Cinnyris asiaticus*) in Bandar Abbas, Honmozgan, South Iran. *Podoces*, **2**(2): 122-126.

Ghazoul, J. 2002. Impact of logging on the richness and diversity of forest butterflies in a tropical dry forest in Thailand. *Biodiv. Conser.*, **11**: 521–541.

Gordan, I. and Cobblah, M. 2000. Insects of the Muni-Pomadze Ramsar site. *Biodiv. Conser.*, **9**: 479-486.

Gotelli, N. J. and Ellison, A. M. 2002. Biogeography at a regional scale: determinants of ant species density in New England bogs and forests. *Ecology*, **83**(6):1604–1609.

Goyer, R. A., Lenhard, G. J. and Smith, J. D. 1990. Insect herbivores of a bald-cypress/tupelo ecosystem. *For. Ecol. Manag.*, **33-34**: 517-521.

Gray, L. J. 1993. Response of insectivorous birds to emerging aquatic insects in riparian habitats of a tallgrass prarie stream. *Am. Mid. Nat.*, **129**: 288-300.

Greenslade, P. J. M. and Greenslade, P. 1984. Invertebrates and environmental assessment. *Environ. Planning*, **3**:13–15.

Gribbin, S. D. and Thompson, D. J. 1990. A quantitative study of mortality at emergence in the damselfly *Pyrrhosoma nymphula* (Sulzer) (Zygoptera: Coenagrionidae). *Freshwater Biology*, **24**: 295-302.

Grimmett, R., Inskipp, S. and Inskipp, R. 2001. Pocket *Guide to the Birds of Indian Sub- Continent.* Oxford University Press. New Delhi.

Guimarães, J. H. and Amorin, D. S. 2006. Diptera, *In*: Eds. Costa, C., Ide, S. and Simonka, C. E. *Insetos imaturos: metamorfose e identificação.* Ribeirão Preto, Holos, pp 147–160.

Guinan, D. M. and Sealy, S. G. 1987. Diet of House Wrens (*Troglodytesa edon*) and the abundance of the invertebrate prey in the dune-ridge forest, Delta Marsh, Manitoba. *Can. J. Zool.*, **65**:1587-1596.

Guinther, E. 2012. *Ecology: A Guide to the Study of Ecosystems.* Downloaded from Wikibooks.org.

Gullan, P. J. and Cranston, P. S. 2000. *The insects: An outline of entomology*. Blackwell Science, Oxford, U K.

Gunathilagaraj, K., Soundararajan, R. J., Chitra, N. and Swamiappan, M. 1999. Odonata in the rice fields of Coimbatore. *Zoo's Print J.,* **14** (6): 43-44.

Gupta, I. J., De, M. L. and Mitra, T. R. 1995. Conspectus of Odonata fauna of Calcutta, India. *Records Zoo. Sur. India,* **95**: 107–121.

Gupta, M. K., Rajan, B. and Baruha, R. 1998. Parakeet damage to sugarcane. *Ind. J. of Sugarcane,* **46**: 961–967.

Gupta, V. K. and Das, B. P. 1977. Distributional patterns of Indian Vespidae (Hymenoptera) with reference to altitude. *Entomon,* **2**: 209-213.

Guruprasad, B. R., Hegde, S. N. and Krishna, M. S. 2010. Seasonal and altitudinal changes in population density of 20 species of *Drosophila* in Chamundi hill. *J. Insect Sci.,* **10**:123.

Gutiérrez, D. and Menéndez, R. 1995. Distribution and Abundance of Butterflies in a Mountain Area in the Northern Iberian Peninsula. *Ecography,* **18**(3) 209-216.

Hadfield, M. G. 1993. Introduction to the symposium: the crisis in invertebrate conservation. *Am. Zoologist*, **33**: 497–498.

Hairston, N. G. 1959. Species abundance and community organization. *Ecology*, **40**: 404-416.

Hamalainen, M. 1994. Dragonflies of Mount Kinabalu (the highest mountain in Borneo). *Malangpo,* **11**: 77–81.

Hands, H. M., Drobney, R. D. and Ryan, M. R. 1989. *Status of the Loggerhead Shrike in north central United States.* Unpublished report of the U. S. Fish and Wildlife Service, Missouri Cooperative Fish Wildlife Research Unit, University of Missouri, Columbia.

Hardersen, S. and Frampton, C. M. 1999. Effects of short term pollution on the level of fluctuating asymmetry – a case study using damselflies. *Entomologia Experimentalis et Applicata,* **92:** 1–7.

Hardy, A. R., Stanley, P. I. and Greeing, S. P. W. 1987. Birds as indicator of the intensity of use of agricultural pesticide in UK. *In:* (Eds.) Diamond, A.W. and Falion, F. N. *The value of birds. Technical Publication,* **6**:119-121.

Haribal, M. 1994. *Butterflies of Sikkim, Himalaya and their natural History*. Sikkim Nature Conservation Foundation, Gangtok.

Hassal, C. and Thompson, D. J. 2008. The effects of environmental warming on Odonata: a review. *Int. J. Odonatology,* **11** (2): 131-153.

Hassanzadeh, M., Pourabad, R. F., Gharaat, M. and Beykpor, A. R. 2009. A study on the Heteroptera fauna of Shend Abad region and Environ (IRAN). *Munis Entomol. Zoo.*, **4**(2): 527-530.

Haviland, M. D. 1925. The Membracidae of Kartabo, Bartica District, British Guiana. *Zoologica* **6:** 229–290.

Hawking, J. H. *and* New, T. R. 2002. Interpreting dragonfly diversity to aid in conservation assessment: lessons from the Odonata assemblage at Middle Creek, north-eastern Victoria, Australia. *J. Insect Conser.,* **6**:171–178.

Heino, J. 2002. Concordance of species richness patterns among multiple freshwater taxa: A regional perspective. *Biodiv. Conser.,* **11**: 137-147.

Hilden, O. 1965. Habitat selection in birds: a review. *Ann. Zool. Fen.,* **2**: 53-75

Hill. M. G. and Blackmore, P. J. M. 1980. Interactions between ants and the coccid *Icerya seychellarum* on Aldabra Atoll. *Oecologia*, **45**: 360-365.

Hill, J. K., Hamer, K. C. and Hodkinson, I. D. 1998. Variation in resource exploitation along an altitudinal gradient - the willow psyllids (*Cacopsylla Spp*.) on Salix lapponum. *Ecography*, **21**: 289–296.

Hodgkin, E. P. and Watson, J. A. L. 1958. Breeding of dragonflies in temporary waters. *Nature,* **181**: 1015-1016.

Hof, C., Brandle, M. and Brandl, R. 2005. Lentic odonates have larger and more northern ranges than lotic species. *J. Biogeog.,* **33**: 63–70.

Hoffmann, B. D. 2010. Using ants for rangeland monitoring: Global patterns in the responses of ant communities to grazing. *Ecol. Indic.,* **10**:105–111.

Hoffmann, B. D., Griffiths, A. D. and Andersen, A. N. 2000. Response of ant community in dry sulfur deposition from mining emission in semi-arid northern Australia, with implications for use of functional groups. *Austral Ecology,* **25**:653-663.

Holldobler, B. and Wilson, E. O. 1990. *The Ants*. Harvard University Press. USA. Pp.732.

Holmes, R. T., Schultz, J. C. and Nothnagle, P. 1979. Bird predation on forest insects: An exclosure experiment. *Science,* **206:** 462–463.

Holway, D. A., Lach L., Suárez A. V., Tsutsui, N. D. and Case T. J. 2002. The causes and consequences of ant invasions. *Ann. Rev. Eco. Sys.,* **33**: 181 – 233.

Hozumi, S., Yamane, S., Miyano, S., Mateus, S. and Zucchi, R. 2005. Diel changes of temperature in the nests of two *Polybia* species, *P. paulista* and *P. occidentalis* (Hymenoptera, Vespidae) in the subtropical climate. *J. Ethol.,* **23:**153-159.

Hu, X. P. 2006. Carpenter Bees– Biology and Management. ANR-1302. Downloaded from: www.aces.edu.com

Hurd, L. E., Mellinger, M. V., Wolf, I. L. and Mc Naughton, S. J. 1971. Stability and diversity in three tropic levels in terrestrial successional ecosystem. *Science,* **173**: 1134-1136.

Hussain, K. J., Ramesh, T., Satpathy, K. K. and Selvanayagam, M. 2011. Seasonal dynamics of butterfly populations in DAE campus, Kalpakkam, Tamil Nadu, South India. *J. Threatened Taxa,* **3**(1): 1401-1414.

Hussain, M. A. and Bhalla, H. R. 1937. The bird enemies of the cotton roller *Svlepta degogata* at Khanewal Multan (Punjab). *Ind. J. Agri. Sci.,* **7**: 785-792.

Hutto, R. L. 1990. Measuring the availability of food resources. *Studies in Avi. Bio.,* **13**:20–28.

Immelmann, K. 1971. Ecological aspects of periodical aspects of reproduction. In: *(*Eds.) Farner, D. S. and King, J. R. *Avian Biology,* Vol I, Academic Press, New York, London.

Itioka, T., Inoue, T., Kaliang, H., Kato, M., Nagmitsu, T., Momose, K., Sakai, S., Yumoto, T., Mohamad, S. U., Hamid, A. A. and Yamane, S. 2001. Six year population fluctuation of the giant honey bee *Apis dorsata* (Hymenoptera: Apidae) in a tropical lowland dipterocarp forest in Sarawak. *Ann. Entomol. Soc. America,* **94**: 545-549.

IUCN 2009. http://www.iucnredlist.org/

IUCN 2011. http://www.iucnredlist.org/

Jain, N. K., Patel, S. N. and Patel, M.V. 2005. Birds of Gujarat University Campus, Ahmedabad. *Zoos' Print J.,* **20** (12): 211-213.

Jalil, M. F., Mahsol, H. F., Wahid, N. and Ahmad, A. H. 2008. A preliminary survey on the butterfly fauna of Sungai Imbak Forest Reserve, a remote area at the centre of Sabah, Malaysia. *J. Tropical Bio. Conser.,* 4 (1): 115 – 120.

Jana, S., Pahari, P. R., Dutta, T. K. and Bhattacharya, T. 2009. Diversity and community structure of aquatic insects in a pond in Midnapore town, West Bengal, India. *J. Environ. Biol.,* **30**: 283-287.

Janzen, D. H. 1973a. Sweep samples of tropical foliage insects: Description of study sites, with data on species abundances and size distributions. *Ecology,* **54** (3): 600-686.

Janzen, D. H. 1973b. Sweep samples of tropical foliage insects: effects of seasons, vegetation types, elevation, time of day and insularity. *Ecology,* **54**(3): 687-708.

Janzen, D. H. 1983. Insects: Introduction. In: Ed. Janzen, D. *Costa Rican Natural History*. University of Chicago, Chicago, Illinois, USA, Pp. 619-644.

Janzen, D. H. 1987a. How moths pass the dry season in a Costa Rican dry forest. *Insect Sci. Appl.,* **8**: 489–500.

Janzen, D. H. 1988. Ecological characterization of a Costa Rican dry forest caterpillar fauna. *Biotropica,* **20**(2):120-135.

Janzen, D. H. and Schoener, T. W. 1968. Differences in insect abundance and diversity between wetter and drier sites during a tropical dry season. *Ecology,* **49**: 96-110.

Janzen, D. H., Ataroff, M., Fari-Nas, M., Reyes, S., Rincon, N., Soler, A., Soriano, P. and Vera, M. 1976. Changes in the arthropod community along an elevational transect in the Venezuelan Andes. *Biotropica,* **8**: 193–203.

Javed, S. and Kaul, R. 2002. *The Field Methods for Birds Surveys*. Bombay Natural History Society, Mumbai.

Jeanne, R. L. 1991. The swarm founding Polistinae. *In:* Eds. Ross, K. G. and Mathews, R. W. *The social biology of wasps.* Cornell University Press, Ithaca, New York, Pp. 191–231.

Jiggins, C. D., McMillan, W. O., Neukirchen W. and Mallet, J. 1996. What can hybrid zones tell us about speciation? *Bio. J. Linnean Soc.,* **59**(3): 221-242.

Johnson, M. D. 2000. Evaluation of an arthropod sampling technique for measuring food availability for forest insectivorous birds. *J. Field Ornithol.,* **71**(1):88-109.

Jones, C. G., Lawton, J. H. and Shachak, M. 2004. Organisms as ecosystem engineers. *Oikos,* **69**: 373-386.

Jonkman, J. C. M. 1978. Nests of the leaf-cutting ant *Atta vollenweideri* as accelerators of succession in pastures. *Z. Ang. Ent.,* **86**: 25-34.

Jonsen, I. D. and Taylor, P. D. 2000. Fine-scale movement behaviors of calopterygid damselflies are influenced by landscape structure: an experimental manipulation. *Oikos*, **88**: 553–562.

Joshi, P. C. 2007. Community structure and habitat selection of butterflies in Rajaji National Park, a moist deciduous forest in Uttaranchal, India. *Tropical Ecology,* **48**(1): 119-123.

Kadoya, T. and Washitani, I. 2007. An Adaptive Management Scheme for Wetland Restoration Incorporating Participatory Monitoring into Scientific Predictions Using Dragonflies as an Indicator Taxon. *Glob. Environm. Res.,* **11**: 179-185.

Kadoya, T., Suda, S. and Washitani, I. 2004. Dragonfly species richness on man-made ponds: effects of pond size and pond age on newly established assemblages. *Ecol. Res*., **19**: 461-467.

Kadoya, T., Suga, S., Tsubaki, Y. and Washitani, I. 2008. The sensitivity of dragonflies to landscape structure differs between life-history groups. *Landscape Ecol.,* **23:** 149–158.

Kai, H. K. and Corlett, T .R. 2002. Seasonality of forest invertebrates in Hong Kong, South China. *J. Tropical Ecol.,* **18**: 637-644.

Kalkman, V. J., Clausnitzer, V., Dijkstra, K. D. B., Orr, A. G., Paulson, D. R. and van Tol, J. 2008. Global diversity of dragonflies (Odonata) in freshwater. *Hydrobiologia,* **595**: 351–363.

Kamura, C. M., Morini, M. S. C., Figueiredo, C. J., Bueno, O. C. and Campos-Farinha, A. E. C. 2007. Ant communities (Hymenoptera: Formicidae) in an urban ecosystem near the Atlantic Rainforest. *Braz. J. Biol.,* **67**(4): 635-641.

Kandibane, M. Mahadevan, N. R. and Gunathilagaraj, K. 2003. Odonata in irrigated rice ecosystem of Madurai, Tamil Nadu. *Zoo's Print J.,* **18**(7): 1155-1156.

Kandibane, M., Raguraman, S. and Ganapathy, N. 2005. Relative abundance and diversity of Odonata in an irrigated rice field of Madurai, Tamil Nadu. *Zoos' Print J.,* **20**(11): 2051-2052.

Kanowski, P. B. 1956. The ants of Ramser Country, North Dakota. *Am. Midl. Nat.,* **56:**168-185.

Kark, S., Iwaniuk, A., Schalimtzek, A., Banker, E. 2007. Living in the city: can anyone become an "Urban exploiter"? *J. Biogeog.,* **34:** 638-651.

Karr, J. R. and Roth, R. R. 1971. Vegetation structure and avian diversity in several new world areas. *Am. Nat.*, **105**: 423-435.

Kaspari, M. 1993. Body size and microclimate use in neotropical granivorous ants. *Oecologia*, **96:** 500–507.

Kaspari, M. and Majer, J. D. 2000. Using Ants to Monitor Environmental Change. In: Eds. Agosti, D., Majer, J., Alonso, E. and Schultz, T. *Ants: Standard Methods for Measuring and Monitoring Biodiversity*. Biological Diversity Handbook Series. Smithsonian Institution Press. Washington D.C. Pp. 89-98.

Kaspari, M. and Weiser, M. D. 2000. Ant activity along moisture gradients in a Neotropical forest. *Biotropica*, **32:** 703–711.

Kaspari, M., O'Donnell, S., Kercher, J. R. 2000. Energy, density, and constraints to species richness: ant assemblages along a productivity gradient. *American Naturalist*, **155:** 280–293.

Kataria, R. 2011. *Towards integrated pest management: an ecofriendly control of insect pests in agricultural fields of Vadodara, Gujarat (INDIA).* Ph.D. Thesis submitted to The M. S. University of Baroda. Vadodara, India.

Kazmierczak, K. 2006. *A field guide to the Birds of India.* Pica Press (An imprint of Helm International Ltd.) East Sussex.

Kehimkar, I. 2008. *The book of Indian butterflie*s. Bombay Natural History Society, Oxford University Press, Mumbai, Delhi, Calcutta, Chennai.

Kennedy, C. E. J. and Southwood, T. R. E. 1984. The number of species of insects associated with British trees: a re-analysis. *J. Animal Eco.*, **53**: 455–478.

Kenyeres, Z. 2006. Phenology, population dynamics and habitat preferences of the Field-cricket (*Gryllus campestris* Linnaeus, 1758) in the Balaton Uplands (Hungary). *Articulata*, **21**(1): 35–44.

Kevan, P. G. 1999. Pollinators as bioindicators of the state of the environment: species, activity and diversity. *Agr. Ecosyst. Environ*., **74**:373–393.

Khan, H. A., Hassan, B. and Mehmood, I. 2006. A Comparison of Population Abundance of the Rose-ringed Parakeet, *Psittacula krameri*, in the Two Roosts of Central Punjab, Pakistan**.** *J. Agri. Social Sci.*, **2**(3): 136–141.

Khanal, B. 2006. The Late Season Butterflies of Koshi Tappu Wildlife Reserve, Eastern Nepal. *Our Nature*, **4**:42-47.

Kim, K.C. 1993. Biodiversity, conservation, and inventory: Why insects matter. *Biodiv. Conser.*, **2**: 191–214. As cited by Simonson *et al.*, 2001, loc. cit.

Kittelson, P. M. 2004. Sources of variation in insect density on *Lupinus arboreus* Sims: effects of environment, source population and plant genotype. *The Am. Midland Nat.***, 152**: 323–335.

Klasing, K. C. 2004. *Comparitive Avian Nutrition –Sh. Rahimi (transl. into Persian)*. Tarbiat Modares University Press, Tehran, Pp 517.

Klein, A. M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C. and Tscharntke, T. 2007. Importance of pollinators in changing landscapes for world crops. *Proc. Royal Soc. Bio. Sci.*, **274**:303–313.

Knight, H. H. 1941. The plant bugs or Miridae of Illinois. *Bul. Illinois Nat. His. Surv.*, **22**: 1-234.

Kohno, K. and Bui Thi, N. 2005. Comparison of the life history strategies of three *Dysdercus* true bugs (Heteroptera: Pyrrhocoridae), with special reference to their seasonal host plant use. *Entomol. Sci.*, **8**: 313–322.

Korkeamaki, E. and Suhonen, J. 2002. Distribution and habitat specialization of species affect local extinction in dragonfly Odonata populations. *Ecography,* **25**: 459-465.

Koskimies, P. 1989. Bird as a tool in environmental monitoring. *Ann. Zool. Fenn.*, **26**: 153-166.

Krebs, C. J. 1985. *Ecology: the experimental analysis of distribution and occurrence*. Third edition, Harper and Row Publishers, New York.

Kremen, C, 1992. Assessing the indicator properties of species assemblages for natural areas monitoring. *Ecological Applications,* **2**:203-217.

Kremen, C., Colwell, R. K., Erwin, T. L., Murphy, D. D., Noss, R. F. and Sanjayan, M. A. 1993. Terrestrial arthropod assemblages — their use in conservation planning. *Conser. Biol.,* **7:** 796–808.

Kricher, J. C. 1972. Bird species diversity: the effect of species richness and equitability on the diversity index. *Ecology,* **53**: 278-282.

Kricher, J. C. 1975. Diversity in two wintering bird communities: possible weather effects. *Auk,* **92**: 766-777.

Krishnaraj, R. and Pritchard, G. 1995. The influence of larval size, temperature and components of the functional response to prey density on growth rates of dragonflies *Lestes disjunctus* and *Coenagrion resolutum* (Insecta: Odonata). *Can. J. Zool.*, **73**: 1672-1680.

Kroll, J. C. and Fleet, R. R. 1979. Impact of woodpecker predation on over-wintering within tree populations of the southern pine beetle (*Dendroctonus frontalis*). *In: (Eds.)* Dickson, J. G., Connor, R. N., Fleet, R. R., Jackson, J. A. and Kroll, J.C. *The role of insectivorous birds in forest ecosystems.* Academic Press, New York, Pp. 269–82.

Kumano, N. and Kasuya, E. 2006. An alternative strategy for maintenance of eusociality after nest destruction: New nest construction in a primitively eusocial wasp. *Insectes Sociaux*, **53**: 149–155.

Kumar, A. 1972. The Phenology of dragonflies in the Dehradun valley (India). *Odonatologica* **1**: 199-207.

Kumar, A. 2002. Odonata diversity in Jharkhand state with special reference to niche specialization in their larval forms, In Kumar, A. (editor). *Current Trends in Odonatology*. Daya Publishing House, Delhi. Pp. 297-314.

Kumar, A. and Mitra, A. 1998. Odonata diversity at Sahastradhara (Sulphur springs), Dehra Dun, India, with notes on their habitat ecology. *Fraseria,* **5** (1/2): 37-45.

Kumar, A., Longino, J. T., Colwell, R. K. and O'Donnell, S. 2009. Elevational Patterns of Diversity and Abundance of Eusocial Paper Wasps (Vespidae) in Costa Rica. *Biotropica,* **41**: 338–346.

Kumar, D and Shiva Kumar, M. S. 2007. Abundance and Diversity of butterflies in Vadodara, Gujarat. *Indian J. Environ. Sci.,* **5**:145-148.

Kumar, D. and Mishra, A. 2008. Ant community variation in urban and agricultural ecosystems in Vadodara District (Gujarat State), western India. *Asian Myrmecology,* **2**:85 – 93.

Kumar, S. M., Srihari, K. T., Nair, P., Varghese, T. and Gadagkar, R. 1997. Ant species richness at selected localities of Bangalore. *Insect Environments,* **3**(1): 3-5.

Kunte, K. 1997. Seasonal patterns in butterfly abundance and species diversity in four tropical habitats in northern Western Ghats. *J. Biosci.,* **22**(5):593-603.

Kunte, K. J. 2000. *India- A lifescape - Butterflies of Peninsular India*. Indian Academy of Sciences, Bangalore and Universities Press, Hyderabad.

Kunte, K. 2000-2001. Butterfly Diversity of Pune City along the Human Impact Gradient. *J. Ecol. Soc.,* **13/14**: 40-45.

Kusnezov, N. 1957. Number of species of ants in faunae of different latitudes. *Evolution,* **11**: 298-299.

Lack, D. 1966. *Population Studies of Birds*. Oxford University Press, London.

Lal, R. 1988. Effects of macrofauna on soil properties in tropical ecosystems. *J. Agri. Eco. Environ.*, **24**:101-116.

Lane, G. 1999. *Alternative pollinators: native bees*. Horticulture Technical Note, NCAT Agriculture Specialist, California.

Larsen, T. B. 1987. The butterflies of the Nilgiri Mountains of Southern India (Lepidoptera: Rhopalocera). *J. Bombay Nat. His. Soc.,* **84**:53.

Larsen, T. B. 1995. Butterflies in Kakum National Park, Ghana. Part 2: Nymphalidae, Hesperiidae., *Ibid*. **54**:43-46.

Lassau, S. and Hochuli, D. 2005. Wasp community responses to habitat complexity in Sydney sandstone forests. *Austral. Ecology,* **30**: 179-187.

Lavelle, P., Spain, A. V., Blanchart, E., Martin, A. and Martin, S. 1992. The impact of soil fauna on the properties of soils in the humid tropics. In: Eds. Sanchez P. A. and Lal, R. *Myths and Science of soils in the tropics.* Madison, Wisconsin: SSSA Special Publ. Pp. 157-185.

Lawler, S. P. 2001. Rice fields as temporary wetlands: a review. *Israel J. Zoo.*, **47**: 513-528.

Le Masne, G. and Bonavita-Cougourdan, A. 1972. Premiers reÂsults tsd'une irradiation pro-longeÂe au ceÂsium sur les populations de fourmis en Haute-Provence. *Ekologia Polska*, **20**: 129 -144.

Lee, P. and Rotenberry, J. T. 2005. Relationships between bird species and tree species assemblages in forested habitats of eastern North America. *J. Biogeo.*, **32**:1139-1150.

Lefroy, H. M. 1905. *Indian Insect Life: A Manual of the Insects of the Plains: (Tropical India).* Today and Tomorrow's Printers and Publishers, New Delhi.

Levings, S. C. 1981. *Some aspects of tropical community structure*. Ph.D. Thesis, Harvard University. Harvard.

Levings, S. C. and Windsor, D. M. 1982. Seasonal and annual variation in litter arthropod populations. In: Eds. Leigh, E.G., Rand, A.S. and Windsor, D.M. *The ecology of a tropical forest*. Smithsonian Institution Press, Washington DC, U S A. Pp. 355-387.

Levings, S. C. and Windsor, D. M. 1985. Litter arthropod populations in a tropical deciduous forest: Relationships between years and arthropod Groups. *J.Animal Ecol.*, **54**(1): 61-69.

Lewis, D. S. 2009. *Lime Swallowtail, Chequered Swallowtail, Citrus Swallowtail Papilio demoleus Linnaeus (Insecta: Lepidoptera: Papilionidae)*. University of Florida (IFAS Extension).

Li, Z. W. D. and Mundkur, T. 2007. Numbers and distribution of waterbirds and wetlands in the Asia-Pacific region. Results of the Asian Waterbird Census: 2002-2004. Wetlands International, Kuala Lumpur, Malaysia.

Linnavuori, R. F. and Hosseini, R. 2000. *Heteroptera of Guilan Part 1*. Guilan University. p.94.

Lobery de Bruyn, L. A. 1993. Ant composition and activity in naturally vegetated and farmland environments on contrasting soils at Kellerberrin, Western Australia. *Soil Biol. Biochem.*, **25**: 1043 -1056.

Lobery de Bruyn, L. A. and Conacher, A. J. 1994. The bioturbation activity of ants in agricultural and naturally vegetated habitats in semi arid environments. *Australian J. Soil Res.*, **32**:555-570.

Long, J. L., 1981. *Introduced Birds of the World: the Worldwide History, Distribution and Influence of Birds Introduced to New Environments*. Newton Abbot, London.

Longino, J. T., Coddington, J. and Colwell, R. K. 2002. The ant fauna of tropical rain forests: Estimating species richness three different ways. *Ecology*, **83**: 689-702.

Louette, M., Bijnens, L., Upoki Agenong, A. D. and Fotso, R. C. 1995. The utility of Birds as bioindicators: case studies in equatorial Africa. *Belgain J. Zool.*, **125**: 157-165.

Lounibos, L. P., Escher, R. L., Dewald, L. B., Nishimura, N. and Larson, V. L. 1990. Odonata associated with water lettuce (*Pistia stratiotes*). *Odonatologica*, **19**: 359-366.

Lourie, S. A. and Tompkins, D. M. 2000. The diets of Malaysian swiftlets. *Ibis*, **142**:596-602.

Lowman M. D. 1982. Seasonal variation in insect abundance among three Australian rain forests, with particular reference to phytophagous types. *Austr. J. Ecol.*, **7**: 353-361.

Loyola, R. D. and Martins, R. P. 2008. Habitat structure components are effective predictors of trap-nesting Hymenoptera diversity. *Basic App. Eco.*, **9** (6): 735-742.

Lubertazzi, M. A. and Ginsberg, H. 2010. Emerging dragonfly diversity at small Rhode Island (U.S.A.) wetlands along an urbanization gradient. *Urban Ecosystems*, **13**(4): 517-533.

Lucky, A., Erwin, T. L. and Witman, J. D. 2002. Temporal and spatial diversity and distribution of arboreal Carabidae (Coleoptera) in a western Amazonian rain forest. *Biotropica*, **34**: 376–386.

Lutz, P. E. 1968. Life history studies of *Lestes erunus* Say (Odonata). *Ecology*, **49**: 576-579.

Lynch, J. F., Balinsky, E. C. and Vail, S. G. 1980. Foraging patterns in three sympatric forest ant species, *Prenolepis imparis*, *Paratrechina melanderi* and *Aphaenogaster rudis* (Hymenoptera: Formicidae). *Eco. Entomol.*, **5:** 353–371.

Mackay, W. P., Rebeles, A., Arredondo, H. C., Rodriguez, A. D., Gonzalez, D. A. and Vinson, S. B.1991. Impact of the slashing and burning of a tropical rain forest on the native ant fauna (Hymenoptera: Formicidae). *Sociobiology*, **18**: 257-268.

Magurran, A. E. 1988. *Ecological diversity and its measurement*. Princeton University Press, Princeton, 177 p.

Mahabal, A. and Bastawade, D. B. 1985. Population ecology and communal roosting behaviour of Pariah kite Milvus migrans govinda in Pune (Maharashtra). J. Bombay Nat. His. Soc., ***82*** *(2): 337–346.*

Mahabal, A. and Bastawade, D.B. 1991. Mixed roosting associates of Indian Myna *Acridotheres tristis* in Pune city, India. *Pavo*, **29** (1 & 2): 23–32.

Mahaulpatha, T., Mahaulpatha, D., Nakane, K. and Fujii, T. 2001. Nestling diet and prey selection of the Japanese Wagtail *Motacilla grandis*. *J. Yamashina Insti.Ornithol.*, **33**:36-43.

Mahmood, S., Mahmood T., Rais, M., Qureshi, I. Z. and Nadeem, M. S. 2010. A Comparative Study on the Populations and Habitats of the Grey Francolin *Francolinus pondicerianus* and the Black Francolin *Francolinus francolinus* in Lehri Nature Park, Punjab, Pakistan. *Podoces*, **5**(1): 42–53.

Maiolini, B. and Carolli, M. 2009. Odonata in Trentino (NE-Italy): historical and recent data. *Stud. Trent. Sci. Nat.*, **84**: 11-18.

Majer J. D. 1983. Ants: bio-indicators of minesite rehabiliation, land-use and land conservation. *Environ. Manag.*, **7**: 375-383.

Majer, J. D., Recher, H. F., Wellington, A. B., Woinarski, J. C. Z. and Yen, A. L. 1997. Invertebrates of eucalypt formations. *In:* (Eds. Williams, J. E. and Woinarski, J. C. Z.) *Eucalypt ecology: individuals to ecosystems*, Cambridge University Press, Cambridge Pp. 278–302.

Malecki, R. A., Blossey, B., Hight, S. D., Schroeder, D., Kok, L. T., Coulson, J. R. 1993. Biological control of purple loosestrife - case for using insects as control agents, after rigorous screening, and for integrating release strategies with research. *Bioscience,* **43**: 680- 686

Mandel, R. D. and Sorenson, C. J. 1982. The role of harvester ant (*Pogonomyrmex occidentalis*) in soil formation. *Soil Sci. Soc. Am. J*., **46**:785- 788.

Marini, L., Fontana, P., Battisti, A. and Gaston, K. J. 2009. Agricultural management, vegetation traits and landscape drive orthopteran and butterfly diversity in a grassland–forest mosaic: a multi-scale approach. *Ins. Conser. Div.,* **2**: 213-220.

Marinoni, R. C. and N. G. Ganho. 2003. Sazonalidade de *Nyssodrysina lignaria* (Bates) (Coleoptera, Cerambycidae, Lamiinae) no Estado do Paraná, Brasil. *Revista Brasileira de Zoologia,* **20**: 141–152.

Martin, A. M. and Stiles, J. A. 1992. On the biology of five species of Swifts (Apodidae, Cyseloidinae) in Costa Rica. *Western Found. Ver. Zool.*, **4** (5): 286-351.

Martinez del Rio, P. C. 2001. The abundance of four bird guilds and their use of plants in a Mexican dry forest- Oak woodland gradient in two contrasting seasons. *Huitzil,* **2** (1):3-14.

Mateson, W. J. 1980. Herbirvory in relation to plant nitrogen content. *An. Rev. Eco. Sys.,* **111**: 119-161.

Mathew, D. N., Narendran, T. C. and Zacharias, V. J. 1978. A comparative study of the feeding habits of certain species of Indian birds affecting agriculture. *J. Bombay Nat. His. Soc.,* **75**(2): 1178-1197.

Mathews, G. and Anto, M. 2007. *In situ* conservation of butterflies through establishment of butterfly gardens: A case study at Peechi, Kerala, India. *Current Science*, **93** (3): 337 – 347.

Maxwell-Lefroy, H. 1908. The red cotton bug (*Dysdercus cingulatus* Fabr.). *Memoirs Dep. Agri. India (Entomological Series),* **2**: 47–58.

May, M. L. 1978. Thermal adaptions of Dragonflies. *Odonatologica*, **7**: 27-47.

May. R. M. 1978. The dynamics and diversity of insect faunas. *In*: Eds. Mound L.A. and Waloff, N. *Diversity of Insect Faunus: 9th Symposium of the Royal Entomological Society*.. Blackwell, Oxford, U.K. Pp. 188-204

McCarty, J. P. 1997. Aquatic characteristics influence the foraging patterns of tree swallows. *The Condor*, **99**: 210-213.

McEvoy, P. B. 1979. Advantages and disadvantages to group living in treehoppers (Homoptera: Membracidae). *Mis. Pub. Entomol. Soc. America*, **11:** 1–13.

McGavin, G. C. 1992. *Insects of the Northern Hemisphere.* Dragons World Ltd. London. p. 192.

McPeek, M. A. 1998. The consequences of changing the top predator in a food web: a comparative experimental approach. *Ecol. Monographs*, **68:** 1–23.

Menhinink, E. F. 1964. A Comparison of Some Species-Individuals Diversity Indices Applied to Samples of Field Insects**.** *Ecology*, **45**(4): 859-861.

Michener, C. D. 1979. Biogeography of bees. *Ann. Missouri Bot. Garden*, **66**: 277-347.

Michener, C. D. 2000. *The Bees of the World*. Johns Hopkins University Press, Baltimore, Maryland.

Miller, J. C. 1993. Insect natural-history, multispecies interactions and biodiversity in ecosystems. Biodiv. Conserv., **3**: 233-241.

Miller P. L. 2007. Dragonflies of the Madurai Kamaraj Universtiy Campus (Tamil Nadu, India). In: Tyagi, B. K. (Ed.) *Odonata: Biology of Dragonflies.* Scientific Publishers, India. Pp 273-322.

Mitra, A. 2007. Larval and Adult Behavioural patterns of some odonates species from Dehradun Valley. In: Tyagi, B. K. (Ed.) *Odonata: Biology of Dragonflies.* Scientific Publishers, India. Pp 323- 341.

Mitsch, W. I. and Gosselink, I. G. 1986. *Wetlands*. Van Nostrand Reinhold, New York.

Mitter, C., Farrel, B. and Wiegmann, B. 1988. The phylogenetic study of adaptive zones: has phytophagy promoted insect diversification? *American Naturalist,* **132**: 107-128.

Monastyrskii, A. L. 2007. Ecological and Biogeographical Characteristics of Butterflies (Lepidoptera, Rhopalocera) of Vietnam. *Entomological Review,* **87**(1): 43–65.

Moncks, C. 2001. Carpenter bee, a major pollinator, http://www. pollinator.com.

Moore, N. W. 1982. Conservation of odonata – first steps towards a world strategy. *Adv. Odonatology,* **1**: 205–211.

Morais, H. C. and Diniz, I. R. 2004. Herbívoros e herbivoria em cerrado: lagartas como exemplo. In: Eds. Aguiar, L. M. S. and Camargo A. J. A. *Cerrado*: ecologia e caracterização. Planaltina, DF: Embrapa‑CPAC. Pp. 159‑175.

Morale, M. A. and Beal, A. L. H. 2006. Effects of Host Plant Quality and Ant Tending for Treehopper *Publilia concave*. *Ann. Entomol. Soc. America: Eco.Pop. Bio.*, **99**(3): 545-552.

Morrison, M. L. 1986. Bird populations as indicators of environmental changes. *Current Ornithol.*, **3:** 429-451.

Murakami, M. 2002. Foraging mode of four insectivorous bird species under temporally varying resources distribution in a Japanese deciduous forest. *Ornithol. Sci.,* **1**: 63-69.

Murali, K. S. and Sukumar, R. 1994. Reproductive phenology of a tropical dry forest in Mudumalai, Southern India. *J. Eco.,* **82**: 759-767.

Murphy, S. M., Kessel, B., Vinning Souce, L. J. 1984. Waterfowl Populations and Limnologic Characteristics of Taiga ponds. *Journal of Wildlife Management,* **48** (4):1156-1163.

Murray, D. L. 2000. A Survey of the Butterfly Fauna of Jatun Sacha, Ecuador (Lepidoptera: Hesperioidea and Papilionoidea). *J. Res. Lep.,* **35**:42–60.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. and Kent, J. 2000. Biodiversity hotspots for conservation priorities. *Nature*, **403**: 853–858.

Nahrung, H. F. and Allen, G. R. 2004. Over wintering ecology of *Chrysophtharta agricola*: mechanisms of reproductive diapause induction and termination. *J. Zool.,* **52**(5): 505-520.

Nakamura, K. and Numata, H. 2006. Effects of photoperiod and temperature on the induction of adult diapause in *Dolycoris baccarum* (L.) (Heteroptera: Pentatomidae) from Osaka and Hokkaido, Japan. *Jap. J. Appl. Entomol. Zool.*, **41**(1): 105-109.

Nash, M. S., Whitford, W. G., Bradford, D. F., Franson, S. E., Neale, A. C., Heggem, D. T. 2001. Ant Communities and Livestock Grazing in the Great Basin, USA. *J. Arid Environ*., **49** (4):695–710.

New, T. R. 1993. Introduction to the Biology and Conservation of Lycaenidae. In: Ed. New, T.R. *Conservation Biology of Lycaenidae (butterflies)* IUCN, Cambridge. 1-21

Newton, I. 1995. The contribution of some recent research on birds to ecological understanding. *J. Ani. Ecol.,* **64**: 675–696.

Nilsson, S. G. and Nilsson, I. N. 1978. Breeding bird community densities and species richness in lakes. *Oikos,* **31**: 214-221.

Noriega, J. A., Botero, J. P., Viola, M. and Fagua, G. 2007. Dinamica estacional de la estructura trofica de un ensamblaje de Coleoptera en la Amazonia Colombiana. *Revista Colombiana de Entomologia*, **33**: 157–164.

Norman, F., Johnson, N. F. L. and Tripplehorn, C. A. 1992. *Borror and DeLong's Introduction to the Study of Insects*. Brooks Cole Publishing, Belmont, *CA.*

Norma-Rashid, Y. 1995. Preliminary odonate survey of Perak, Peninsular Malaysia. *Notul. Odonatol.* **4**: 80–82.

Norma-Rashid, Y. Mohd-Sofian, A. and Zakaria-Ismail, M. 2001.Diversity and distribution of Odonata (dragonflies and damselflies) in the fresh water swamp lake Tasek Bera, Malaysia. *Hydrobiologia*, **459:** 135–146.

Norma-Rashid, Y., Zakaria-Ismail, M. and Hamalainen, M. 1996. Odonate fauna from Kelantan, Pahang and Muar drainages, Malaysia. *Proc.. 5th Nat. Bio. Symposium*, UKM, Malaysia.

Novotny, V. and Basset, Y. 2000. Rare species in communities of tropical insect herbivores: pondering the mystery of singletons. *Oikos*, **89:** 564–572.

Ntiamoa-Baidu, Y., Owusu, E. and Daramani, D. T. 2000. Terrestrial birds of the Muni-Pomadze Ramsar site. *Biodiv. Conser.,* **9**: 511–525.

Nudds, T. 1983. Variation in richness, evenness and diversity in diving and dabbling ducks guilds in prairie pothole habitats. *Can. J. Zool.,* **61**:1547-1550.

O'Connell, T. J., Jackson, L. E and Brooks, R. P. 2000. Bird guilds as indicators of Ecological Condition in the Central Appalachians. *Ecol. Appl.,* **10** (6):1706-1721.

O'Donnell, S., and Joyce, F. J. 2001. Seasonality and colony composition in a montane tropical eusocial wasp. *Biotropica*, **33**: 727–732.

Oertli, B. Joye, D. A., Castella, E., Juge, R., Cambin, D. and Lachavanne, J. B. 2002. Does size matter? The relationship between pond area and biodiversity. *Bio. Conserv*., **104**: 59–70

Oldroyd, B. P. and Nanork, P. 2009. Conservation of Asian honey bees. *Apidologie*, **40**: 296–312**.**

Oliveira, P. S. and Brandão, C. R. F. 1991. The ant community, associated with extrafloral nectaries in the Brazilian cerrados. *In:* Eds. Huxley, C. R. and Cutler, D. F. *Ant-plant interations*, Oxford University Press, Oxford, England. pp. 182-212.

Oliver, I. and Beattie, A. J. 1996. Invertebrate morphospecies as surrogates for species: a case study. *Conser. Biol.*, **10**: 99-109.

Olson, D. M. 1994. The distribution of leaf litter invertebrates along a Neotropical altitudinal gradient. *J. Tropical Eco.,* **10**:129-150.

Ott, A. P., Azevedo-Filho W. S., Ferrari, A. and Carvalho, G. S. 2006. Abundância e sazonalidade de cigarrinhas (Hemiptera, Cicadellidae, Cicadellinae) em vegetação herbácea de pomar de laranja doce, no município de Montenegro, Estado do Rio Grande do Sul, Brazil. *Iheringia, Série Zoologia*, **96**: 425–429.

Ott, J. 2007. The expansion of *Crocothemis erythraea* (Brulle, 1832) in Germany – An indicator of Climatic changes. In: Tyagi, B. K. (Ed.) *Odonata: Biology of Dragonflies.* Scientific Publishers, India. Pp. 273-322.

Padate, G. S., Sapna, S. and Devkar, R. V. 2001. Status of Birds in Vadodara District (Central Gujarat). *Pavo,* **39** (1, 2): 83-94.

Padmalatha Rai, S., Ramachandra, Y. L. and Sujan Ganapathy, P. S. 2007. Herb and Shrub Bee Plants and their Blooming Period in Shankaraghatta. *Environ. Eco.*, **25S** (4A): 1360-1363.

Pande, S., Pawashe, A., Sant, N. and Mahabal, A. 2004. Status, habitat preferences and population estimates of non-breeding shrikes *Lanius* spp. in Maharashtra and Karnataka states, India. *Biol. Letters*, **41**(2): 65.69.

Pandey, J. S., Joseph, V. and Kaul, S. N. 2004. A Zone-Wise Ecological-Economic Analysis of Indian Wetlands. *Environ. Monit. Assess.*, **98**: 261–273.

Pandharipande, T. N. 1990. Butterflies from Nagpur city, Central India (Lepidoptera: Rhapalocera). *J. Res. Lep.*, **29**(1-2): 157-160.

Paraceullos, M. 2006. How can habitat selection affect the use of a wetland complex by water birds? *Biodiv. Conser.*, **15**: 4569-4582.

Parasharya, B. M. and Jani, J. J. 2007. *Butterflies of Gujarat*. Anand Agricultural University, Anand, Gujarat, India.

Parasharya, B. M., Dodia, J. F., Yadav, D. N. and Patel, R. C. 1988. Effect of bird predation and egg parasitism on castor semilooper *Achaca janata* Linn. (Lepidoptera: Noctuidae) in Gujarat. *J. Biol. Conser.,* **2**:80-82.

Parasharya, B. M., Dodia, J. F., Mathew, K. L and Yadav, D. N. 1994. Natural regulation of white grub (*Holotrichia* sp. Scaralidae) by birds in agroecosystem. *J. Biosci*., **19** (4): 381-390.

Parikh, P., Sonavane, S. and Ahir, K. 2008. Diversity of diptera in Gir PA. *J. Cur. Sci.,* **12**(2): 711-716.

Partridge, L. 1978. Field and laboratory observations on the foraging and feeding techniques of Blue tits *Parus caeruleans* and Coal tits *Parus ater* in relation to their habitat. *Anim. Behav.,* **24**: 534-544.

Patel, H. M., Yadav, D. N., Parasharya, B. M. and Patel, R. C. 1987. A note on predation of *Catopsilia sp.* (Lepidoptera: Pieridae) by birds and wasp. *J.Bomb. Nat. Hist. Soc.,* **84**: 452-454.

Patil J. V. 2011. *Study of selected faunal biodiversity of Toranmal area, Toranmal Reserve forest.* Ph.D. Thesis submitted to The Maharahja Sayajirao University of Baroda Vadodara, Gujarat, India.

Patterson, J. H. 1976. The role of environmental heterogeneity in the regulation of duck populations. *Journal of Wildlife Management,* **40**(1): 22-32.

Pearce, M. J. 1997. Termites, Biology and Pest Management. CAB International , Willing Ford UK., Pp: 172. As Cited by Kumar and Pardeshi, 2011. *Loc. cit.*

Pearson, D. L. 1994. Selecting indicator taxa for the quantitative assessment of biodiversity. *Phil. Trans. Royal Soc. Lond.,* **345**:75-79.

Peixoto, P. and Benson, W. W. 2009. Daily activity patterns of two co-occuring tropical satyrine butterflies. *J. Insect Sci.,* **9**:54.

Perez, L., Monroy, D. and Realpe, E. 2007. Local assemblage patterns of Odonates in Central Choco, Colombian Pacific. In: Tyagi, B. K. (Ed.) *Odonata: Biology of Dragonflies.* Scientific Publishers, India. Pp. 183-199.

Perfecto, I. and Snelling, R. 1995. Biodiversity and the transformation of the tropical agro ecosystem: ants in coffee plantations. *Ecol. Appl.,* **5**:1084-1097.

Petal, J. 1976. The effect of mineral fertilization on ant populations in meadows. *Pol. Ecol. Stud.,* **2**: 209-218.

Petal, J. 1978a. Adaptation of ants to industrial pollution. *Memorabilia Zoologia,* **29**: 99-108.

Petal, J. 1978b. The role of ants in Ecosystems. In: Ed. Brian, M. V. *Production Ecology of Ants and Termites.* Cambridge University Press Cambridge, UK. Pp. 293-325.

Petal, J. 1992. The role of ants in nutrient cycling in forest ecosystems. In: Ed. Billen, J. *Biology and Evolution of Social Insects.* Leuven University Press, Leuven, Pp. 167-170.

Petal, J., Jakubczyk, H., Chmielewski, K. and Tatur, A. 1975. Response of ants to environmental pollution. In: Ed. Vabek, J. *Progress in Soil*. Prague: Czechoslovakia Academy of Sciences. Pp. 363- 373

Petterson, R. P., Ball, J. P., Renhorn, K., Esseen, P. and Sjoberg, K. 1995. Invertebrate communities in boreal forest canopies as influenced by forestry and lichens with implications for passerine birds. *Biol. Conser.,* **74**: 57-63.

Pimmental. S. L. 1986. Community stability and structure. In: Ed. Soulé, M. E *Conservation Biology: The Science of Scarcity and Diversity.* Sinauer Associates, Sunderland, M A. U.S.A. Pp. 309-329.

Pinheiro, F., Diniz, I. R., Coelho, D. and Bandeira, M. P. S. 2002. Seasonal pattern of insect abundance in the Brazilian cerrado. *Austral. Ecology,* **27**: 132–136.

Pisarski, B. 1978. Comparison of various biomes. In: Ed. Brian, M.V. *Production Ecology of Ants and Termites*. Cambridge Univ. Press, Cambridge, UK. Pp. 325-332.

Polhemus, J. T. and Polhemus, D. A. 2008. Global diversity of true bugs (Heteroptera: Insecta) in freshwater. *Hydrobiologia,* **595**: 379–391.

Pollard, E. 1979. Population ecology and change in range of the White Admiral butterfly *Ladoga camilla* L. in England. *Eco. Entomol.,* **4**: 61–74.

Pollard, E. 1988. Temperature, rainfall and butterfly numbers. *J. Appl. Eco.,* **25**(3): 819–828.

Pollard, E. and Yates, T. J. 1993. *Monitoring Butterflies for Ecology and Conservation*. Chapman and Hall, London.

Pollard, E. 1991. Monitoring butterfly numbers. In: Ed. Goldsmith F. B. *Monitoring for Conservation and Ecology*. Chapman and Hall, London. Pp 87

Potts, S., Vulliamy, B., Roberts, S., O'toole, C., Dafni, A., Ne'eman, G. and Willmer, P. 2005. Role of nesting resources in organising diverse bee communities in a mediterranean landscape. *Eco. Entomol.,* **30**: 78-85.

Powell, G. V. N. 1987. Habitat use by wading birds in a semitropical estuary: implications of hydrography. *Auk*, **104**: 740-749.

Prasad, M. 1999. *Faunal diversity in India: Odonata*. Zoological Survey of India, Calcutta. 171-178.

Prasad, M. 2002. Odonata diversity in Western Himalaya, India. In Kumar, A. (editor). *Current Trends in Odonatology*. 377 pp. Daya Publishing House, Delhi, pp. 221-254

Pratt, H. D., Bruner, P. L. and Berrett, D. G. 1987. *A Field Guide to the Birds of Hawaii and the Tropical Pacific.* Princeton Univ. Press, Princeton, N J.

Price, P.W. 2002. Species interactions and the evolution of biodiversity. *In*: Eds. Herrera, C. M. and Pellmyr, O. *Plant-animal interactions: an evolutionary approach.* Blackwell Science, Oxford. Pp. 3–25.

Pryke, S. R. and Samways, M. 2001. Width of grassland linkages for the conservation of butterflies in South African afforested areas. ***Bio. Conser.,*** **101**: 85-96

Pulliam, H. R. 1974. On the theory of optimal diets. *Am. Nat.*, **108**: 59-74.

Purse, B.V. and Thompson, D. J. 2003. Emergence of damselflies *Coenagrion mercuriale* and *Coenagrion tenellum* (Odonata: Coenagrionidae), at their northern range margins, in Britian. *Eu. J. Entomol.*, **100**: 93-99.

Putman, R. J., Edwards, P. J., Mann, J. C. E., How, R. C. and Hill, S. D. 1989. Vegetational and faunal changes in an area of heavily grazed woodland following relief of grazing. *Biol. Conserv.,* **47**:13–32.

Putman, R.J. 1995. *Community ecology*. Chapman and Hall, London.

Rabb, R. L. 1960. Biological studies of *Polistes*. North Carolina (Hymenoptera: Vespidae). *Ann. Entomol. Soc. Am*., **53**: 111–121.

Rabello, A. R., Queirozi, P. R., Simoes, K. C. C., Hiragi, C. O., Lima, L. H. C., Oliveira, M. R. V. and Mehta, A. 2008. Diversity analysis of *Bemisia tabaci* biotypes: RAPD, PCR-RFLP and sequencing of the ITS1 rDNA region. *Genetics and Molecular Biology*, **31**(2): 585-590.

Radford, B. J., Key, A. J., Robertson, L. N. and Thomas, G. A. 1995. Conservation tillage increases soil water storage, soil animal populations, grain yield, and response to fertiliser in the semi-arid tropics. *Austr. J. Exp. Agric*., **35**: 223-232.

Ragaei, M. and Allam, M. 1997. Insect Conservation and Diversity. *J. Islamic Acad. Sci.*, **10**(2):43-48.

Rahbek, C. 2005. The role of spatial scale and the perception of large-scale species-richness patterns. *Ecol. Letters*, **8**: 224–239.

Rai, S., Ahi, J., Jain, R. and Jain, N. 2011. Histopathological Effect of Fenoxycarb on Ovary of *Poekilocerus pictus (Fabr)* (Orthoptera:Acrididae). *As. J. Exp. Bio. Sci.,* **2**(3):433-440.

Rajagopal, T., Sekar, M., Manimozhi, A., Baskar, N. and Archunan, A. 2011. Diversity and community structure of Agrignar Anna Zoological Park, Chennai, Tamil Nadu. *J. Environ. Bio.,* **32**:201-207. .

Rajpar, M. N. and Zakaria, M. 2010. Density and diversity of water birds and Terrestrial birds at Paya Indah wetland Reserve, Selangor Peninsular Malaysia. *J. Bio. Sci.,* **10**(7): 658-666.

Ramachandra, T., Kiran, A., Ahylaya, N. and Deepa R.S. 2002. Status of wetlands of Bangalore. Technical Report 86. Available at www.wgbis.ces.iisc.ernet.in/energy/TR86/welcome.html

Ramesh, T., Hussain K. J., Satpathy, K. K., Selvanayagam, M. and Prasad M. V. R. 2010. Diversity, Distribution and Species composition of Ants fauna at Department of Atomic Energy (DAE) campus Kalpakkam, South India. *World J. Zoo.*, **5** (1): 56-65.

Ramesh, T., Hussain, K. J., Selvanayagam, M., Satpathy, K. K. and Prasad, M. V. R. 2010. Patterns of diversity, abundance and habitat associations of butterfly communities in heterogeneous landscapes of the department of atomic energy (DAE) campus at Kalpakkam, South India. *Int. J. Biodiv. Conser.*, **2**(4): 75-85.

Rana, B. D. and Idris, M. 1987. Food Habits of the House Sparrow Passer domesticus indicus in an Arid Environment. *Jap. J. Ornithol.*, **35**: 125-128.

Rana, S. V. S. 2005. *Essentials of Ecology and Environmental Science*. 2nd Edition Prentice-Hall of India Private Ltd., New Delhi.

Rangnekar, P., Borkar, M. and Dharwadkar, O. 2010. Additions to the Odonata (Insecta) of Goa. *J. Threat. Taxa*, **2**(4): 805-814.

Rathod, J. Y. 2009. *Avifauna of urban area: Its significance and implication under various human disturbances*. Ph. D. Thesis submitted to the M. S. University of Baroda, Vadodara, India.

Raut, N. B. and Pendharkar, A. 2010. Butterfly (Rhopalocera) fauna of Maharastra Nature Park, Mumbai, Maharastra, India. *J. Species Lists Distri.*, **6**(1): 22-25.

Read, J. L. and Andersen, A. N. 2000. The value of ants as early warning bioindicators: responses to pulsed cattle grazing at an Australian arid zone locality. *J. Arid Environ.*, **45:** 231–251

Reece, B. A. and Mcintyre, N. E. 2009. Community assemblage patterns of odonates inhabiting a wetland complex influenced by anthropogenic disturbance. *In. Conser. Diver.*, **2:** 73–80.

Rees, C. J. C. 1983. Microclimate and the flying Hemiptera fauna of a primary lowland rain forest in Sulawesi. In: Eds. Sutton, S. L., Whitmore, T. C. and Chadwick, A. C. *Tropical Rain Forest: Ecology and Management*, Blackwell Scientific Publications, Oxford. Pp. 121–36.

Rehn, A. C. 2003. Phylogenetic analysis of higher-level relationships of Odonata. *Syst. Entomol.*, **28**: 181–239.

Richard, A. J. 2001. Does low biodiversity resulting from modern agricultural practice affect crop pollination and yield? *Ann. Botany*, **88**:165–172.

Richards, O. W. and Davies, R. G. 1984. *Imm's General Text book of Entomology*. Volume II, 10th Edition, Champman and Hall, London.

Richter, M. R. 2000. Social wasp (Hymenoptera: Vespidae) foraging behavior. *Ann. Rev. Entomol.*, **45**: 121–150.

Ricklefs, R., Naveh, E. Z. and Turner, R. E. 1984. Conservation of ecological processes. Commission on Ecology Papers Number 8. *Environmentalist*, **4**(Supplement No. 8): 3-16.

Rith-Najarian, J. C. 1998. The influence of forest vegetation variables on the distribution and diversity of dragonflies in a northern Minnesota forest landscape: a preliminary study (Anisoptera). *Odonatologica,* **27**: 335–351.

Roberts, T. J. 1991. *The Birds of Pakistan*. Vol. I, Oxford University Press, Oxford. U.K. Pp. 230–233.

Robinson, M. H. and Robinson, B. 1970. Prey caught by a sample population of the spider *Argiope argentata* (Araneae: Araneidae) in Panama: A year's census data. *Zoo. J. Linnean Soc.*, **49**: 345-358.

Rodewald, P. G. and James, R. D. 1996. Yellow throated Vireo (*Vireo flavifrons*). *In*: (Eds) Poole, A. and Gill, F. *The Birds of North America*. The Academy of Natural Sciences, Philadelphia, Pennsylvania, USA, and The American Ornithologist Union, Washington, D.C., USA.

Rodgers, W. A. 1991. *Techniques for wildlife census in India: A field manual*. Wildlife Institute of India, Dehradun, India.

Rohit, A. R. 2001. *An inventory of butterfly diversity in vicinity of Anand*. M.Sc. Thesis submitted to Gujarat Agricultural University, Anand.

Rosenberg, D. M., Danks, H. V. and Lehmkuhl, D. M. 1986. Importance of insects in environmental impact assessment. *Environ. Manag.,* **10**: 773–783.

Rosenberg, K. V., Ohmart, R. D., Hunter, W. C. and Anderson, B. W. 1991. *Birds of the lower Colorado River Valley*. Univ. of Arizona Press, Tucson.

Rosenzweig, M. L. 1995. *Species Diversity in Space and Time*. Cambridge University Press, Cambridge.

Rotenberry, J. 1978. Components of avian diversity along a multifactorial gradient. *Ecology*, **59**: 693-699.

Rotenberry, J., Fitzner, R. and Rickard, W. 1979. Seasonal variation in avian community structure: differences in mechanisms regulating diversity. *Auk*, **96**:499-505.

Roughgarden J. 1972. Evolution of niche width. *Am. Nat.*, **106**: 683–718.

Roy, P., Leo, R., Thomas, S. G., Varghese, A., Sharma, K., Prasad, S., Bradbear, N., Roberts, S., Potts, S. G. and Davidar, P. 2011. Nesting requirements of the rock bee *Apis dorsata* in the Nilgiri Biosphere Reserve, India. *Tropical Ecology*, **52**(3): 285-291.

Runck, C. and Blinn, D.W. 1994**.** Role of *Belastoma bakeri* (Heteroptera) in the trophic ecology of a fishless desert spring. *Limnol. Oceanogra.,* **39**(8): 1800-1812.

Ruszczyk, A. 1986. Distribution and Abundance of Butterflies in the Urbanization zones of Porte Alegre, Brazil. *J. Res. Lep.*, **25**(3): 157-178.

Sabu, T. K., Vineesh, P. J. and Vinod, K. V. 2008. Diversity of forest litter-inhabiting ants along elevations in the Wayanad region of the Western Ghats. *J. Insect Sci.,* **8**: 14pp.

Safavi, M. 1973. Clede determination des families d’ Hemipteres Heteroteres de l Iran. *J. Entomol. Soc. Iran*, **1**(1): 3-11.

Saha, N., Aditya G., Bal, A. and Saha G. K. 2007. Comparative study of Functional Response of Common Hemipteran Bugs of East Calcutta Wetlands, India. *Int. Rev. Hydrobio.,* **92**(3):242-257.

Sahlén, G. 1999. The impact of forestry on dragonfly diversity in Central Sweden. *Int. J. Odonatol.*, **2**: 177–186.

Sahlén, G. 2006. Specialists vs. generalists in the Odonata – the importance of forest environments in the formation of diverse species pools. *Forests and Dragonflies (Proceedings of Fourth World Dragonfly Association International Symposium of Odonatology, Pontevedra, Spain, July 2005)* (ed. by A.C. Rivera), Pensoft Publishers, Sofia, Russia. Pp. 153–179.

Sahlen, G. and Ekestubbe, K. 2001. Identification of dragonflies (Odonata) as indicators of general species richness in boreal forest lakes. *Biodiv. Conser.,* **10**: 673-690.

Saikia, M. K., Kalita, J. and Saikia, P. K. 2009. Ecology and conservation needs of nymphalid butterflies in disturbed tropical forest of Eastern Himalayan biodiversity hotspot, Assam, India. *Int. J. Biodiv. Conser.,* **1**(7): 231-250.

Salem, M. and Hole, F. 1968. Ant (*Formica exectoides*) Pedoturbacion in a Forest Soil. *Soil Sci. Soc. America*, **32**:563-567.

Samejima, H., Marzuki, M., Nagamitsu, T. and Nakasizuka, T. 2004. The effects of human disturbance on a stingless bee community in a tropical rainforest. *Bio. Conser.,* **120**: 577-587.

Sample B. E., Cooper, R. J. and Whitmore, R. C. 1993. Dietary shifts among songbirds from diflubenzuron treated forest. *Condor*, **95**:616-625.

Samson, D. A., Rickart, E. A. and Gonzales, P. C. 1997. Ant diversity and abundance along an elevational gradient in the Phillippines. *Biotropica,* **29:**349-363.

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

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

Samways, M. J. Caldwell, P. M. and Osborn R. 1996. Spatial patterns of dragonflies (Odonata) as indicators for design of conservation pond. *Odonatologica*, **25**(2): 157-166.

Sanders, N. J., Barton, K. E. and Gordon, D. M. 2001. Long-term dynamics of the distribution of the invasive Argentine ant, *Linepithema humile*, and native ant taxa in northern California. *Oecologia*, **127**: 123-130.

Savard, L. J., Clergeau, P. and Mennechez, G. 1998. Biodiversity concepts and urban ecosystems. *Landscape and Urban Planning*, **48** (3-4): 131-142.

Schindler, M., Fesl, C. and Chovanec, A. 2003. Dragonfly associations (Insecta: Odonata) in relation to habitat variables: a multivariate approach. *Hydrobiologia*, **497**: 169-180.

Schneider, C. 2003. *The Influence of Landscape Structure on Butterfly Diversity and Movement in Grasslands: a comparison of two agricultural areas in Southern Sweden*. Ph. D. thesis submitted to the Swedish University of Agricultural Sciences,Sweden.

Schumacher, A. and Whitford, W. G. 1976. Spatial and temporal variation in Chihuahuan desert ant faunas. *Southwestern Naturalist*, **21:** 1–8.

Scoble, M. 1992. *The Lepidoptera: form, function and diversity*. Oxford University Press, Oxford.

Scott, J. M., Mountainspring, S., Ramsey, F. L. and Kepler, C. B. 1986. *Forest Birds Communities of Hawaiian Islands: their dynamics, ecology, and conservation. Series: Studies in Avian Biology 9*. Cooper Ornithological Society, Allen Press Inc., Lawrence, ES.

Scougall, S. A., Majer, J. D. and Hobbs, R. J. 1993. Edge effects in grazed and ungrazed Western Australian wheat belt remnants in relation to ecosystem reconstruction. In: Eds. Saunders, D. A., Hobbs, R. J. and Ehrlich, P. R. *Nature Conservation 3: Reconstruction of Fragmented Ecosystems*, Surrey Beatty and Sons, Chipping Norton. Pp. 163–178.

Scudder, G. G. E. 1996. Terrestrial and freshwater invertebrate of British Columbia: priorities for inventory and descriptive research. Working Paper 09/1996. Research Branch, BC Ministry of Environment, Lands and Parks. Victoria, BC. Pp. 206

Sealy, S. G. 1980. Reproductive response of Northem Orioles to a changing food supply. *Can. J. Zool.*, **58**: 221-227**.**

Seeley, T. D., Seeley, R. H. and Akratanakul, P. 1982. Colony defence strategies of the honeybees in Thailand. *Ecological Monographs,* **52**: 43-63.

Sepp, K., Mikk, M. and Ma¨nd, M. 2004. Bumblebee communities as an indicator for landscape survey in the agri-environmental programme. *Landsc. Urban. Plan*., **67**:173–183.

Shafi, M. M., Khan, A. A. and Hussain, I. 1986. Parakeet damage to citrus fruit in Punjab. *J. Bombay Nat. His. Soc.*, **83**: 439–444.

Shakarad, M. and Gadagkar, R. 1995. Colony founding in the primitively eusocial paper wasp, *Ropalidia marginata* (Lep.) (Hymenoptera: Vespidae). *Ecol. Entomol*., **20**:273–282.

Shanthi, R., Hussain, K. J. and Sanjayan, K. P. 2009. Influence of weather on the incidence of sucking pest complex on summer-irrigated cotton crops of Tamil Nadu. *Hexapoda,* **16**(1): 89-92.

Sharma, G. and Joshi, P. C. 2007. Diversity of Odonata (Insecta) from Dholbaha dam (Dist. Hoshiarpur) in Punjab Shivalik, India. *J. Asia-Pacific Entomol.*, **10**(2): 177-180.

Sharma, G., Ramamurthy, V. V. and Kumar, R. 2009. Collection of damselflies and dragonflies (Odonata : Insecta) in National Pusa Collection, Division of Entomology, Indian Agricultural Research Institute, New Delhi, India. *Biological Forum,* **1**(2): 47-50.

Sharma, G., Sundararaj, R. and Karibasvaraja, L. R. 2007. Species diversity of Odonata in the selected provenances of Sandal in Southern India. *Zoos' Print J.,* **22**(7): 2765-2767.

Sharmila, E. J. 2009. Butterflies of Hawa valley in a reserve forest – Tamil Nadu. *Current Biotica,* **3** (2):135-142.

Shelton, M. D. and Edward, C. R. 1983. Effects of weeds on the diversity and abundance of insects in soyabeans. *Environ. Entomol*., **12**:296-299.

Shruthi, S. D., Ramachandra, Y. L. and Sujan Ganapathy, P. S. 2009. Studies on Behavioural Traits of Two Different Strains of Indian Honey Bee *Apis cerana indica* F., *World App. Sci. J.,* **7** (6): 797-801.

Silsby, J. 2001. *Dragonflies of the World.* Smithsonian Institution Press, Washington, D.C., Pp. 216.

Silva, R. R. and and Brandão, C. R. F. 2010. Morphological patterns and community organization in leaf-litter ant assemblages. *Ecological Monographs,* **80**:107–124.

Silva, R. R., Feitosa, R. S. M. and Eberhardt, F. 2007. Reduced ant diversity along a habitat regeneration gradient in the southern Brazilian Atlantic Forest. *Forest Eco. Manag.*, **240** (1–3):61–69.

Silva, N. A. P., Frizzas, M. R. and Oliveira, C. M. 2011 Seasonality in insect abundance in the "Cerrado" of Goiás State, Brazil. *Revista Brasileira de Entomologia,* **55**(1): 79–87.

Silveira, O. T., Costa Neto, S. V. and da Silveira, O. F. 2008. Social wasps of two wetland ecosystems in Brazilian Amazonia (Hymenoptera, Vespidae, Polistinae). *Acta Amozanica,* **38**(2): 333 - 344.

Silvestre, R., Dem´etrio, M. F. and Delabie, J. H. C. 2012. Community Structure of Leaf-Litter Ants in a Neotropical Dry Forest: A Biogeographic Approach to Explain Betadiversity**.** *Psyche,* 2012, Article ID 306925, 15 pages

Simonson, S. E., Opler, P. A., Stohlgren, T. J. and Chongi, G. W. 2001. Rapid assessment of butterfly diversity in a montane landscape. *Biodiv. Conserv.,* **10**: 1369–1386.

Singh, A. 2011. *Adoption of Biorational alternatives to pesticides in selected agricultural crops.* Ph.D. Thesis submitted to The M. S. University of Baroda. Vadodara, India.

Sivakumaran, N. and Thiyagasen, K. 2003. Population, Diurnal activity patterns and feeding ecology of the Indian Roller *Coracias bengalensis* (Linnaeus, 1758). *Zoo's Print J.,* **18** (5): 1091-1095.

Smallwood, K. S. and Schonewald, C. 1996. Scaling population density and spatial pattern for terrestrial, mammalian carnivores. *Oecologia*, **105**:329–335.

Smith, 1992. *Elements of Ecology*. 3rd Edition, Harper Collins Publishers Ltd., London.

Smith, J., Samways, M. J. and Taylor, S. 2006. Assessing Riparian Quality Using Two Complementary Sets of Bioindicators. *Biodiv. Conser.*, **16** (9): 2695-2713.

Smith, K. and MacMohan, J. 1981. Bird communities along a montane sere, community structure and energetics. *Auk,* **98**:8-28.

Smolka, G. E., Stewart, P. M. and Swinford, T. O. 1999. Distribution of odonates (Dragonflies and Damselflies) in the Indiana Dunes National Lakeshore and Nearby Lands. *Natural Areas J.*, **19**: 132– 141.

Sobek, S., Gobner, M. M., Scherber, C., Steffan- Dewenter, I. and Scharntke, T. 2009. Tree diversity drives abundance and spatiotemporal β-diversity of true bugs (Heteroptera). *Ecol. Entomol.*, **34**, 772–782.

Raju, A. J. 2004. Nectar host plants of some butterfly species at Visakhapatnam. *Science and Culture*, **70**: 187–190.

Raju, S. A. J. and Rao, P. S. 2006. Nesting habits, floral resources and foraging ecology of large carpenter bees (*Xylocopa latipes* and *Xylocopa pubescens*) in India. *Current Science*, **90** (9): 1210-1217.

South, J. M. and Pruett-Jones, S. 2000. Patterns of flock size, diet, and vigilance of naturalized monk parakeets in Hyde Park, Chicago. *Condor,* **102**:848–854.

Spungis, V. 2005. Fauna and ecology of bugs (Hemiptera, Heteroptera) in the coastal grey dunes in Latvia. – *Latvijas Entomologs,* **42**: 95-105.

Sreekumar, P. G. and Balakrishnan, M. 2001. Habitat and altitude preferences of butterflies in Aralam Wildlife Sanctuary, Kerala. *Tropical Ecology*, **42**(2): 277-281.

Stattersfield, A. and Capper, D. 2000. *Threatened Birds of the World*. Lynx Editions and Birdlife International, Barcelona and Cambridge.

Stefanescu, C., Penuelas, J. and Filella, I. 2009. Rapid changes in butterfly communities following the abandonment of grasslands: a case study. *Insect Conser. Div.*, **2**:261–269.

Sternberg, K. 1994. Niche specialization in Dragonflies. *Adv. Odonatology*, **6**: 177-198.

Stewart, D. A. B. and Samways, M. J. 1998. Conserving dragonfly (Odonata) assemblages relative to river dynamics in an African Savanna game reserve. *Conser. Bio*., **12**: 683-692.

Steytler, N. S. and Samways M. J. 1995. Biotope selection by adult male dragonflies (Odonata) at an artificial lake created for insect conservation in South Africa. *Bio. Conser.*, **72**: 381-386.

Stiles, F. G. 1995. Behavioral, Ecological and Morphological Correlates of Foraging for Arthropods by the Humming birds of a Tropical Wet Forest. *Condor,* **97**:853-878.

Stork, N. E. 1988. Insect diversity: facts, fiction and speculation. *Biol. J. Lin. Soc*., **35**: 321-333.

Stork, N. E. and Brendell, M. J. D. 1990. Variation in the insect fauna of Sulawesi trees with season, altitude and forest type. *In*: Eds. Knight W. J. and Holloway, J. D. *Insects and the Rain Forest of South East Asia (Wallacea).* Royal Entomological Society of London, London, Pp. 173-190.

Strong, A. M., Sherry, T. W. and Holmes, R. T. 2000. Bird predation on herbivorous insects: indirect effects on sugar maple. *Oecologia*, **125**:370-379.

Stuart, S. N., Chanson, J. S., Cox, N. A., Young, B. E., Rodrigues, A. S. L., Fischman, D. L. and Waller, R. W. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science,* **306:** 1783–1786.

Suarez, A. V, Bolger, D. T, Case, T. J. 1998**.** Effects of fragmentation and invasion on native ant communities in coastal southern California. *Ecology,* **79:** 2041–2056.

Subramaniam, K. A. 2005. *Dragonflies and Damselflies of Peninsular India-A Field Guide*. E-Book of Project Lifescape. Centre for Ecological Sciences, Indian Institue of Science and Indian Academy of Sciences, Bangalore, India. 118 pages.

Subramaniam, K. A. 2007. Endemic Odonats of the Western Ghats: Habitat Distribution and Conservation. In: Tyagi, B. K. (Ed.) *Odonata: Biology of Dragonflies.* Scientific Publishers, India. Pp 273-322.

Subramaniam, K. A., Ali, S. and Ramachandra, T. V. 2008. Odonata as indicators of riparian ecosystem health: A case study from South Western Karnataka, India. *Fraseria* (N.S.), **7:** 83-95.

Subramaniam , K. A. 2009. *A Checklist of Odonata (Insecta) of India.* Zoological Survey of India, Pune, India.

Sudd, J. H. 1987. Ants as partners. *In:* Ed. Sudd, J. H. *The behavioral ecology of ants*. Chapman & Hall, New York. Pp.120-136.

Suh, A. N. and Samways, M. J. 2005. Significance of temporal changes when designing a reservoir for conservation of dragonfly diversity. *Biodiv.Conser*., **14**: 165-178.

Suhling, F., Schenk, K., Padeffke, T. and Martens, A. 2004. A field study of larval development in a dragonfly assemblage in African desert ponds (Odonata). *Hydrobiologia,* **528**: 75-85.

Suhling, F., Sahlen, G., Kasperski, J. and Gaedecke, D. 2005. Behavioural and life history traits in temporary and perennial waters: comparisons among three pairs of sibling dragonfly species. *Oikos,* **108**: 609-617.

Suhling, F., Sahlen, G., Martens, A., Marais, E. and Schutte, C. 2006. Dragonfly assemblage composition and diversity in arid tropical environments: a case study from western Namibia. *Biodiv.Conser.,* **15**: 311–332.

Sundufu, A. and Dumbuya, R. 2008. Habitat preferences of butterflies in the Bumbuna forest, Northern Sierra Leona. *J. Insect Sci.,* **8**:64.

Takamura, K., Hatakeyama, S. and Shiraishi, H. 1991. Odonate larvae as an indicator of pesticide contamination. *Appl. Entomol. Zool.*, **26**: 321-326.

Tam, N. F. Y. and Wong, W. S. 2000. Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps. *Environ. Poll.*, **1**: 195-205.

Tanaka, S. 2000. The role of moisture in the control of diapause and mating and aggregation in a tropical insect. *Entomological Science,* **3**: 147-155.

Tauber, M. J. and Tauber, C. A. 1976. Insect seasonality: Diapause maintenance, termination and post diapause development. *Ann. Rev. Entomol.,* **21**: 81-107.

Taylor, P. D. and Merriam, G. 1995. Wing morphology of a forest damselfly is related to landscape structure. *Oikos*, **73:** 43–48.

Taylor, R. J. and Doran, N., 2001. Use of terrestrial invertebrates as indicators of the ecological sustainability of forest management under the Montreal process. *J. Insect Conser.,* **5:** 221–231.

Teer, J. G. 1995. Rangeland Habitat: Its evaluation and Management for Wildlife. In: Eds. Berwick, S. H and Saharia, V. B. *The development of International Principles and Practices of Wildlife Research and Management Asian and American Approaches.* Milton Book Company, Dehradun, India. Pp. 175-192.

Temple, S. A. and Wiens, J. A. 1989. Bird populations and environmental changes: can birds be bio-indicators? *Am. Birds,* **43**: 260–270.

Teskey, H. J. 1991. Introduction. *In*: Foote, B. A. (Coord.). Order Diptera, cap. 37, *In*: Ed. Stehr, F. W. *Immature insects.* Dubunque, Kendall/Hunt Publishing Company, 2, Pp. 690–706.

Thomas, C. D. 1991. Habitat use and geographic ranges of butterflies from the wet lowlands of Costa Rica. *Bio. Conser.*, **55**: 269-281.

Thomas, C. D. and Malorie, H. C. 1985. Rarity, species richness, and conservation: Butterflies of the Atlas Mountains in Morocco. *Bio. Conser.*, **33**: 95–117. as cited by Simonson *et al.,*2001 *loc. cit.*

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., Erasmus, B. F. N., de Siqueira, M. F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A. S., Midgley, G. F., Miles, L., Ortega-Huerta, M. A., Peterson, A.T., Phillips, O. L. and Williams, S. E. 2004. Extinction risk from climate change. *Nature,* **427**: 145–148.

Thomas, J. A. 2005. Monitoring change in the abundance and distribution of insects using butterflies and their indicator groups. *Phil. Trans. Royal Soc.* (B), **360**: 339–357.

Thomas, S. G., Rehel, M. S., Varghese, A., Davidar, P. and Potts, S. G. 2009. Social bees and food plant associations in the Nilgiri Biosphere Reserve, India. *Tropical Ecology,* **50**: 79-88.

Tilman, D. and Downing, J. A. 1994. Biodiversity and stability in grasslands. *Nature*, **367**: 363-365.

Tiple, A. D., Khurad, A. M. and Dennis, R. L. H. *2007. Butterfly* diversity in relation to a human-impact gradient on an Indian university campus. *Nota Lepidopterol*., 30(1):179-188.

Tiple, A. D. and Khurad, A. M. 2009. Butterfly Species Diversity, Habitats and Seasonal Distribution in and Around Nagpur City, Central India. *World J. Zoo.,* **4** (3): 153-162.

Tiple, A. D., Khurad, A. M. and Dennis, R. L. H. 2011. Butterfly larval host plant use in a tropical urban context: Life history associations, herbivory, and landscape factors. *J. Insect Sci.,* **11**:65.

Toor, H. S. and Saini, M. S. 1986. Feeding ecology of large grey babbler *Turdoides malcolmi. Proc. Ind. Acad. Sci. (Animal Science)***, 95** (4): 429-436**.**

Torossian, C. and Causse, R. 1968. Effets des radiations gamma sur la fertliteÂ et la longeÂ viteÂ des colonies de Dolichoderus quadripunctatus. Compte rendu du Colloque ``Isotopes and radiation in entomology. *International Atomic Energy Agency*, Vienna. Pp. 155-164.

Torres, F. R. and Madi-Ravazzi, L. 2006. Seasonal variation in natural populations of *Drosophila* spp. (Diptera) in two woodlands in the State of São Paulo, Brazil. *Iheringia, Série Zoologia***, 96**: 437–444.

Traynor, J. 1966. Increasing the Pollinating Efficiency of Honeybees. *Bee World*, **47**(3): 101-110.

Trevino, J. 1997. Dragonfly naiads as an indicator of water quality. Technical Note No. 99. *Watershed Protection Technique*, **2**: 533-535.

Turner, W. R. 2003. Citywide biological monitoring as a tool for ecology and conservation in urban landscapes: the case of the Tucson Bird Count. *Landscape and Urban Planning,* **65**: 149-166.

Tyagi, B. K. 1997. Dragonfly Wealth of India: Extant species- a preliminary systematic list. *Zoo's Print J.*, **12**: 3-10.

Tyagi, B. K. 2007. *Odonata: Biology of Dragonflies.* Scientific Publishers, Jodhpur, India.

Ubukata, H. 1973. Life history and behavior of a corduliid dragonfly, *Cordulin aenea amurensis* Selys. 1. Emergence and pre-reproductive periods. *J. Fac. Sci*. *Hokkaido Univ*. *Ser. VI, Zoo*, **19**: 251-269.

Underwood, E. C. and Fisher, B. L. 2006. The role of ants in conservation monitoring: if, when, and how. *Bio.Conser.*, **132:** 166–182.

Urfi, A. J., Sen, M., Kalam, A. and Meganathan, T. 2005. Counting birds in India: Methodologies and Trends. *Current Science*, **89** (12): 1997-2003.

Van der Vecht, J. 1941. The Indo-Australian species of the genus *Ropalidia* (Icaria) (Hym., Vespidae), First part. *Treubia Deel*, **18**:103–190.

Van der Vecht, J. 1962. The Indo-Australian species of the genus *Ropalidia* (Icaria) (Hymenoptera, Vespidae), Second part. *Zool. Verhandelingen,* **57:** 1–71.

Van Doesburg, P. H. Jr. 1968. A revision of the new world species of Dysdercus Guérin Méneville (Heteroptera, Pyrrhocoridae*). Zoologische Verhandelingen*, **97**:1–215.

Van Valen L.1965. Morphological variation and width of ecological niche. *Am. Nat.,* **99**:377–389.

Vanquez, D. P., Aschero, V. and Stevani, E. L. 2008. Livestock grazing, habitat protection and diversity of bees and wasps in the Central Monte desert. *Revista de la Sociedad Entomológica Argentina,* **67** (3-4): 1-10.

Vashishth, N., Joshi, P. C. and Singh, A. 2002. Odonata community dynamics in Rajaji National Park, India. *Fraseria,* **7**(1/2): 21-25.

Velasco, J., Millán, A. and Ramírez-Díaz, L. 1993. Colonización y sucesión de nuevos medios acuáticos II. Variación temporal de la composición y estructura de las comunidades de insectos. *Limnética,* **9**: 87-98.

Vennila, S. 2011. Cotton pests, predators and parasitoids: Descriptions and seasonal dynamics. Downloaded from www.cicr.gov.in

Vijayan, V. S. 1975. *The ecological isolation of Bulbuls (Pycnonotidae) with special reference to Pycnonotus cafer cafer and P. luteolus luteolus at Point Calimere, Tamil Nadu.* Ph.D. Thesis, University of Bombay, Bombay India.

Vineesh, P. J. 2007. *Ecology and diversity of Entomofauna in the litter stands of monoculture and natural forests in Kannur district.* Ph.D Thesis submitted to the University of Calicut, Kerala, India.

Vu, L. V. and Vu, C. Q. 2011. Diversity Pattern of Butterfly Communities (Lepidoptera, Papilionoidae) in Different Habitat Types in a Tropical Rain Forest of Southern Vietnam. *ISRN Zoology*, Article ID 818545, 8 pages.

Wadatkar, J. S. and Kasambe, R. 2008. Butterflies of Melghat Tiger Reserve, Maharastra with notes on their occurrence, status and larval host plants. *The Ecoscan*, **2**(2): 165-171.

Walker, E. M. and Corbet, P. S. 1975. *The Odonata of Canada and Alaska*. Vol. 3. University of Toronto Press, Toronto, ON. Pp 307.

Way, M. J. 1963. Mutualism between ants and honeydew-producing Homoptera. *An. Rev. Entomol.*, **8**: 307-344.

Weir, J. S. 1974. Odonata collected in and near seasonal pools in Wankie National Park, Rhodesia with notes on the physio-chemical environments in which nymphs were found. *J. Entomol. Soc. South Africa,* **37**: 135-145.

Weller, M. W. 1999. *Wetland birds: habitat resources and conservation implications*. Cambridge University Press, Cambridge. Pp. 288.

Weller, M. W. and Spatcher, C. S. 1965. Role of habitat in the distribution and abundance of marsh birds. Special Report 43. Agricultural and Home Economics Experiment Station. Iowa State College, Ames, Iowa, USA.

Weller, M.W. 1978. Management of freshwater marshes for wildlife. In: Good, R. E. Whingham, D. F. and Simpson R. L. (eds.) *Freshwater Wetlands: Ecological process and management potential*. Academic Press, New York.

Wenzel, J. W. 1998. A generic key to the nests of hornets, yellowjackets, and paper wasps worldwide (Vespidae: Vespinae, Polistinae). *American Museum Novitates*, **3324**: 1–40.

Westrich, P. 1996. *Habitat Requirements of Central European Bees and the Problems of Partial Habitats.* Linnaean Society Symposium Series, Academic Press Limited, London.

Whitford, W. G., Depree, D. J., Hamilton, P. and Ettershank, G. 1981. Foraging ecology of seed-harvesting ants, *Pheidole spp.* in a Chihuahuan Desert ecosystem New Mexico. *Am. Midland Nat.*, **105:** 159–167.

Wigglesworth, V. B. 1964. *The life of Insects*. Weidenfeld and Nicolson, London.

Willard, J. R. 1973. Soil invertebrates: III. Collembola and minor insects: populations and biomass. Matador Project. Technical Report 19 Saskatoon, Sask.

Williams, D. D. 1997. Temporary ponds and their invertebrate communities. *Aquatic Conserv.: Marine Freshwater Ecosys.*, **7**: 105-117.

Williams, I. H. 1996. Aspects of bee diversity and crop pollination in the European Union. *In*: Eds. Matheson, A., Buchman, S.L., O'Tool, C., Westridge, P., Williams, I. H. *The conservation of bees*, Academic Press, London.

Williams, P. H. 1998. An annonated checklist of bumble bees with an analysis of patterns of description (Hymenoptera: Apidae, Bombini). *Bull. Nat. Hist. Mus.* (*Entomol*.), **67:** 79–152.

Williams, P. H., Cameron, S. A., Hines, H. M., Cederberg, B. and Rasmont, P. 2008. A simplified subgeneric classification of the bumble bees (genus *Bombus*). *Apidologie*, **39:** 1–29.

Wilson E. O. 1976. Which are the most prevalent ant genera? *Studia Entomol*ogy, **19**: 187-200.

Wilson, E. O. 1987. The little things that run the world: The importance and conservation of invertebrates. *Conserv. Biol*., **1**(4): 344-346.

Wilson, E. O. 1988. The current state of biological diversity. In: Ed. Wilson, E. O. *Biodiversity*. National Academy Press, Washington DC, Pp. 3-18.

Wilson, M. F. 1992. The ecology of seed dispersal. *In*: Ed. Fenner, M. *Seeds: the ecology of regeneration in plant communities.* CAB International , Wallingford, UK, Pp. 61-86.

Windsor, D. M. 1976. Birds and predators on the brood of *Polybia* wasps (Hymenoptera: Vespidae: Polistinae) in a Costa Rica deciduous forest. *Biotropica*, **8**: 111–116.

Woinarski, J. C. Z., Andersen, A. N., Churchill, T. B. and Ash, A. J. 2002. Response of ant and terrestrial spider assemblages to pastoral and military land use, and to landscape position, in tropical savanna woodland in northern Australia. *Austral Ecology*, **27**: 324–333.

Wolda, H. 1977. Fluctuations in abundance of some Homoptera in a neotropical forest. *Geo-Eco-Trop.,* **3**: 229-257.

Wolda, H. 1978. Seasonal fluctuations in rainfall, food and abundance of tropical insects. *J. Animal Eco.,* **47**: 369–381.

Wolda, H. 1988. Insect seasonality: why? *Ann. Rev. Eco. Sys.,* **19**: 1–18.

Wolda, H. 1990. Food availability for an insectivore and how to measure it. *Stu. Avi. Biol.,* **13**:38–43.

Wolda, H. and Denlinger, D. L. 1984. Diapause in a large aggregation of a tropical beetle. *Ecol. Entomol.,* **9**: 217-30.

Wolda, H. and Fisk, F. W. 1981. Seasonality of tropical insects. II. Blattaria in Panama. *J. Ani. Ecol.,* **50**: 827–838.

Wood, T. K. 1977. Role of parent females and attendant ants in maturation of the treehopper, *Entylia bactriana* (Homoptera: Membracidae). *Sociobiology*, **2**: 257–272.

Wood, T. K. 1979. Sociality in the Membracidae (Homoptera). *Mis. Pub. Entomol. Soc. America,* **11**: 15–22.

Wood, T. K. 1984. Life history patterns of tropical membracids (Homoptera: Membracidae). *Sociobiology*, **8**: 299–344.

Wrubleski, D. A. and Ross, L. C. M. 2011. Aquatic Invertebrates of Prairie Wetlands: Community Composition, Ecological Roles, and Impacts of Agriculture. *In*: Ed. Floate, K. D. *Arthropods of Canadian Grasslands (Volume 2): Inhabitants of a Changing Landscape.* Biological Survey of Canada. Pp. 91-116.

Xie, Z., Williams, P. H. and Tang, Y. 2008.The effect of grazing on bumblebees in the high rangelands of the eastern Tibetan Plateau of Sichuan. *J. Insect Conserv*., **12**: 695-703.

Yek, S. H., Williams, S. E., Burwell, C. J., Robson, S. K. A. and Crozier, R. H. 2009. Ground dwelling ants as surrogates for establishing conservation priorities in the Australian wet tropics. *J. Insect Sci.,* **9**:12-23.

Young, M. 1997. *The natural history of moths*. T & A Poyser, London.

Zedler, J. B. and Kercher, S. 2005. Wetland Resources: Status, Trends, Ecosystem Services, and Restorability. *Annu. Rev. Environ. Resour*., **30**: 39–74.