

Influence of different land use corridors on insect pests and insect natural enemy guilds of paddy agro-ecosystems

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*I dedicate this piece of work to my father and mother,
I also dedicate this thesis to Late Mr. Chandrashekara Gowda,
without his vision, wisdom, prayers, and constant care,
this work would not have completed,
I miss him a lot...*



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CERTIFICATE

This is to certify that this thesis entitled ‘ **Influence of different land use corridors on insect pests and insect natural enemy guilds of paddy agro-ecosystems**’ is an authentic record of bonafide research work carried out by Sri. P.A.Sinu, from July 2001 to August 2005, under my supervision and guidance, and that no report of this work has been presented before for any other degree or diploma. It is further certified that Sri. P.A. Sinu passed the Ph.D. preliminary examination held on 20th June, 2003, conducted by the University of Calicut.

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Declaration

I hereby declare that this thesis entitled **Influence of different land use corridors on insect pests and insect natural enemy guilds of paddy agro-ecosystems** is carried out by me under the supervision of Dr. M.Nasser, Lecturer, Department of Zoology, University of Calicut, in partial fulfillment for Ph.D. degree of the University of Calicut, and I also declare that no part of this thesis has been submitted by me for the award of any degree and diploma.

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Chapter 1

INTRODUCTION

The increasing socio economic needs exacerbate pressure on tropical rain forests across the globe (Bawa *et al.* 2004), which threatens much of the regions natural biological diversity. The changing landscape levels and decrease in natural habitats cause a drastic reduction, as well as, massive extinction of native biological diversity. The increasing rate of forest fragmentation in tropics, mainly due to the shifting agriculture practices during ancient times and several latest developments like mining and hydroelectric projects, has created several small discontinuous forest fragments of various sizes, which now locates in a matrix of various land use types. This generates tremendous amount of interests in the discipline called landscape ecology, which emphasizes broad spatial scales as well as the ecological effects of these spatial patterning of ecosystems. Landscape studies specifically deals with various issues like development and dynamics of spatial heterogeneity, interactions and exchanges across heterogeneous landscapes, the influences of spatial heterogeneity on biotic and abiotic processes and the management of spatial heterogeneity (Turner 1987).

Habitat loss and forest fragmentation are becoming a serious impediment to the biological control of insect pests, particularly within managed systems such as agro-ecosystems. However, the impact of these ecosystem processes would be more severe in

an agro-landscape, where the success of natural pest management by the native natural enemies is attributed mainly to the well-being and heterogeneity of the adjacent land use types. A number of studies (Taylor 1988, Hassell *et al.* 1991, Murdoch *et al.* 1992, Kruess and Tschardtke 1994, With *et al.* 2002) have demonstrated that the pest out break in various agro-landscapes around the globe happens only due to the destabilization of the structural diversity and heterogeneity of the adjacent natural habitats. The impact of fragmentation would be tremendous, if it reaches a level that can influence the movement and prey searching behaviour of natural enemies in an agro-landscape. In a study, Thies & Tschardtke (1999) demonstrated that the parasitism rate in the agricultural landscapes declined when the percent of adjacent non-crop area shrunk below 20 %. This has promoted interest in wildlife friendly farming (Green *et al.* 2005). "Beetle banks" and "Island habitats" of farmlands (MacLeod *et al.* 2004) in UK, and throughout the European cereal fields are good examples of the wild life friendly farming. Intensive farming practices, which include large scale use of fertilizers and pesticides, and irrigation, are found to be the other threats to the wild life value of farmlands. Although changing farming practices and deforestation is a threat to the wild life in farmlands everywhere, the impact is greatest in the developing countries. Green *et al.* (2005) in their study found that intensified farming practices is the single biggest threat to the bird faunal composition both in developed and developing part of the world.

Numerous studies have shown that maintaining good vegetational diversity adjacent to farmlands lead to increased natural enemy build up in the farm land, thereby reducing the pest density (Root 1973, Andow 1991). As in other tropical countries, leaving some uncultivated lands adjacent to farmlands is a traditional farming system in India too. These uncultivated lands in several parts of India are the remnants of earlier natural forests. However, due to overexploitation, the natural vegetation in these uncultivated lands is being simplified in most of the developing countries. In most cases, these natural vegetation are being replaced by monoculture tree based plantations, and horticultural crops. These kinds of massive land simplifications directly affect the stability of an agro-ecosystem, which lead to increased pest out break (Andow 1991).

Rice is the staple food for half of the world's population, and is the major food for people living in developing countries. 90 % of the world's total rice production and consumption occurs in Asia. In most of the rice producing countries, folklore activities of the people are linked to the rice cultivation and harvesting. About 80% of the world's rice is grown by small-scale farmers ^{with living in} in low-income and developing countries.

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India has the world's largest area under rice cultivation. In India rice is cultivated in almost all the states, but West Bengal, Uttar Pradesh, Madhya Pradesh, Orissa and Bihar are the major rice producing states (FAO 2004). Rice is the staple food for 65% of the total population in India. There are three major seasons for rice cultivation in India: the early *Kharif* growing season lasts from March-May to June-October; the *mid-Kharif* season from June-October to November-February, and the *Rabi* season from November-February to March-June. Rice-based production systems provide the main income and employment for more than 50 million households. Although the country exports several varieties of rice, many scientists have expressed concern that current Indian rice production techniques cannot sustain the growing domestic population.

Small fields characterize traditional rice farming lands in Asian countries. Many of the irrigated rice paddy fields are usually with bunds of various sizes and shapes. Bunds in the irrigated rice paddy lands are often with a moderate number of wild flora, which comprise both permanent as well as seasonal vegetation. In some parts, the bunds are wider and farmers seasonally cultivate vegetables on these bunds. It has also been observed that these bunds can act as summer refugia for the arthropod natural enemies during fallow period as well as during inundation of paddy field. Biological diversity of traditional rice cultivated fields is akin or even higher than many of the natural ecosystems (Schoenly *et al.* 1998). Due to the continued presence of fresh water, wetland rice fields are habitat for a wide variety of terrestrial and aquatic organisms. Rice fields also host many arthropod natural enemies like parasitoids and predators, which provide a mechanism to control harmful insects and pests, thus reducing the need for pesticides.

The cultivated rice paddy land of Sringeri area of *Malnad* region is only about 9.19 % of the total geographical area. Most of the cultivated lands are small fields, which are surrounded by various kinds of land use types. In most of the villages, rice paddy fields are located adjacent to Areca orchards or natural secondary forests, but rarely near

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Acacia plantations. The farmers in Sringeri depend on the southwest monsoon for the paddy cultivation, and generally enjoy only one cultivation season, which lasts from June - December. But, farmers living close to Tunga river and other major rivulets enjoy two cultivation seasons, mid *Kharif* and *Rabi*, but only very few farmers cultivate in the second season. However, the rice paddy fields of Sringeri area is on the brink of extinction. The major threat to this unique wetland ecosystem is the extensive land conversion to Areca orchards, residential plots, and very recently to ginger cultivation.

The broad objective of this research is to analyze the impact of stand simplifications in the surrounding uncultivated areas, on natural enemy build-up and pest population in the rice paddy agro-landscapes. Thereby, the study intends to test a major hypothesis, *natural enemy hypothesis*, in the theme 'conservation biological control'. The essence of *Natural Enemy hypothesis* is that predators and parasites are more effective in complex environments than the simple ones (Root 1973). The study was carried out in rice paddy agro-landscapes of Sringeri area of the central Western Ghats in India.

1.1 OUTLINE OF THE THESIS

The thesis comprises of six Chapters. In this first chapter, a general introduction of the problem, and the essence of the hypothesis tested, and outline of the study area is given. Second chapter deals with the study area in detail; this chapter constitutes the history and land use changes of the Western Ghats, the land use practices of the *Malnad* region of the Western Ghats, and detailed land use changes and forest management of Sringeri village ecosystems. A comprehensive description of the *Soppinabetta* forests, and its importance to the local community is also given in this chapter. Chapter 3 describes the arthropod and vegetation community ecology of rice paddy agro-landscapes of Sringeri. Field characteristics of each of the 21 study sites, arthropod, soil and vegetation sampling techniques and exploratory results etc. are given in this chapter. Chapter 4 is the main body of this thesis, where the impact of various land use types/ stand simplification on arthropod natural enemy build ups, and pest density in rice paddy agro-landscapes of Sringeri village ecosystem are analyzed; the 'natural enemy hypothesis' is also tested and discussed in this Chapter. In Chapter 5, I have studied the role of generalist predatory

arthropods of rice paddy agro-ecosystems, with a case study on tiger beetle feeding ecology in cultivated rice paddy agro-ecosystems. In Chapter 6, the farming practices, and changing scenario of rice cultivation in Sringeri, and farmers use of *Soppinabetta* forests is described. The summary and concluding remarks are also given in this Chapter. The reference for the selected citations, appendices, and plates follow this Chapter.

Chapter 2

STUDY AREA

The Study was carried out in the Western Ghats, during the period 2003-2004. The Western Ghats is recognized as one of the mega biodiversity hotspots of the world, along with Sri Lanka (Myers *et al.* 2000). The high rate of endemism, unique flora and faunal composition of the hilly regions of the Western Ghats, categorize it as a globally important ecoregion. It is also the most thickly populated biodiversity hotspot in the 21 proclaimed ones (Cincotta *et al.* 2000). In the following sessions of this chapter, the importance of the Western Ghats, its history, land use change in these hilly regions, and details about the study sites are given. sections!

2.1 THE WESTERN GHATS

The Western Ghats, as part of the Malabar biogeographic region, runs parallel to the Arabian sea, north south between 8° - 21° N latitudes – a distance of c. 1600 km in south India. Except a 30 km wide gap at 11° , that is called Palghat gap, it is a continuous hilly region. Hills are generally of elevations between 600 – 1000 m, and the ~~largest~~ ^{higher} peaks above 1000 m are found between 8 and 13° N and 18 and 19° N. However the largest peak in the Western Ghats, which is scaled 2000 asl is found at 11° N at Nilgiri hills. The Western Ghats zone encompasses a considerable gradient of temperature and rain fall; annual rainfall usually averages 2,500 mm. Agumbe (13 – 14° N), ~~that~~ ^{receives} ~~locates~~ 20 km North of Sringeri (the present study area), ~~is~~ ^{highest} the largest rainfall ~~area~~ in the entire Western ?
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Ghats as well as in south India, where the rainfall usually ranges between 5000 – 6000 mm and sometimes reaches up to 7600 mm. The wettest season in the Western Ghats lies between June – October due to the south west monsoon. However mean temperature in the zone ranges between 20 – 24 ~~deg~~ C, and usually dips as low as 0° C in High hilly regions like Nilgiris to above 30° C above 13° N.

The Western Ghats is one of the major Tropical Evergreen Forest regions. Moist evergreen forests extend up to 16° N, and the heavy human use of the forest in the past, above 16° N, left the hills largely barren, and with small fragments of secondary forests towards the rivers and valleys. Champion and Seth (1968), and Pascal (1988), have surveyed the vegetation and flora of the Western Ghats in detail.

2.1.1 The ecological history and human impact in the Western Ghats.

The Western Ghats first came under human influence during the Palaeolithic or Old Stone Age, over 12,000 years before the present (BP, Chandran 1997). However, agriculture and domestication of livestock started about 3,500 years BP in the Western Ghats. Arrival of agriculture and pastoralism are identified as the major reasons, which led towards the drastic ecological changes in the Western Ghats (Gadgil and Guha 1992). However, very little is recorded about the early history of human influence in the Western Ghats.

The hunter-gatherer human community in the palaeolithic age then turned shifting cultivators by the end of Megalithic Age, approximately 3,500 years BP. Whilst, the slash and burn agricultural practices developed 1,000 years BP, which was later banned during British colonization in late 19th century (Chandran 1997, Gadgil and Guha 1992). Because of the harsh climatic conditions and frequent windbreak in hilly regions above 1,000 msl, the pastoralists restricted their activity below this level. Nevertheless, the indigenous people, who believed forests are the properties of the village gods, kept many pieces of the land untouched as the sacred places through out the Western Ghats, which do develop a stake in conserving the natural biological resources (Gadgil *et al.* 1993). These were the major pre-colonial forest reserves, which are called as *devrai* in Maharashtra, *devarakadu* in Karnataka and *kavu* in Kerala and Tamil Nadu (Gadgil and Vartak 1974, Unnikrishnan 1995).

The European occupation, at least 700 years BP, as indicated in the Palynological history (Chandran 1997) was a milestone in the historical period of the Western Ghats, where they started exploiting the evergreen forests on the western slope of the Ghats for timber trade and cultivation of spices like pepper and *malabathrum* (*Cinnamomum malabathrum*) (Sastry 1975). The occupation of this area around 1799 by the British Colonialists after defeating Tipu Sultan, the then ruler of the present central Western Ghats region, had had a tremendous impact in the history of the Western Ghat forestry operations (Chandran 1997) in India. During British rule, the major loss of the evergreen tracts of the Western Ghats happened due to two main reasons; 1) increased timber exploitation, resulted in the mushrooming of monoculture plantations like Teak, Pine, Wattle, Coffee, tea etc. for their timber and commercial value, and 2) the encroachment into the remote high altitude hilly regions to make summer retreats for the British rulers (Gadgil and Guha 1992). The practices of monoculture plantations then continued and grew even after India's independence in 1947.

2.1.2 The Landscape and the history of land use changes in the Malnad region of Karnataka state in the central Western Ghats during British colonization

The *Malnad* (high altitude hilly region) of Karnataka state comprises mainly of three districts, *Uttara Kannada* (formerly North Canara or Karwar District), Shimoga (*Shivamogha*) and Chikmagalur, with some parts of Hassan, Dakshina Kannada districts (However, in this study, *Malnad* region will be used only for U. Kannada, Shimoga and Chikmagalur Districts, which lies fully with in the Western Ghats).

In India, the state initiated forest management started with the declaration of the Charter of Indian Forest in 1855; followed by forest acts in 1865, 1894, 1927 and 1952. The management methods were meant for the timber production and harvesting (Gadgil 1991, Chandran 1997) and promotion of forest based industries. Until the fourth plan period in 1970, the 39 million ha reserve forests were managed solely for timber, firewood and bamboo and another 34 million ha of minor forests were located in the protected forests, village forests and private forests, which were intended to meet the day to day demands of the people for the natural resources and Non Timber Forest Products (NTFPs).

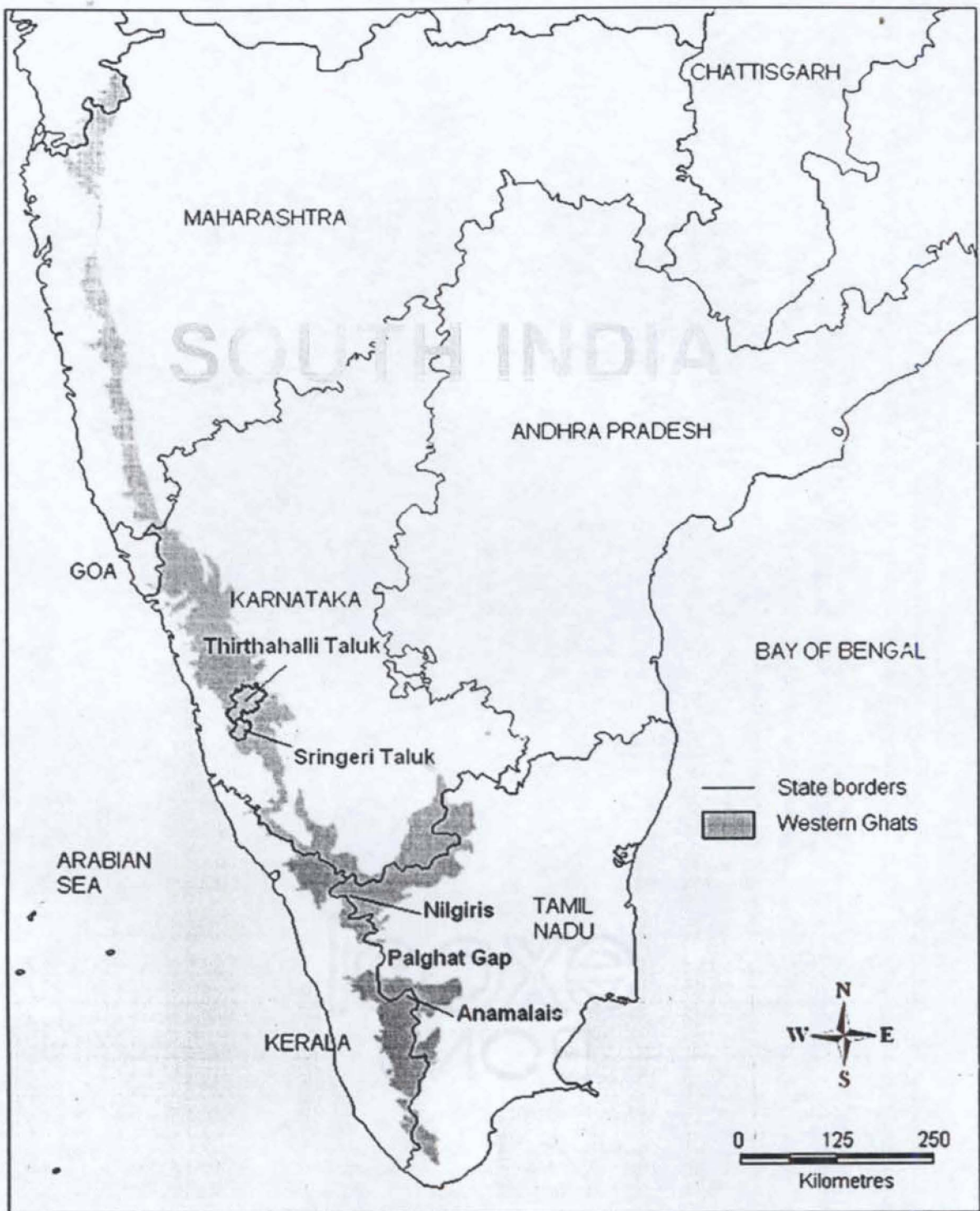


Figure 2.1. Extend of the Western Ghats with study area

The pre-colonial conservation strategies in the *Malnaad* region were mainly centred around the sacred groves, *kans* and other tree based conservation (Gadgil 1988). *Kans* are the small tracts of evergreen forest patches of primary or secondary growth, which were kept alive by the local people for joint forest management (JFM) through out *Malnaad*, mainly for the cultivation of pepper (Manasu in Kannada), which are called as the *Menasukans* or pepper forests. However, the relics of these unique practices are now seen only in parts of Shimoga and Uttara Kannada district in *Malnaad* (Chandran 1997). Although the sacred lands, and *kans* were the traditional and pre-scientific conservation efforts of the indigenous community throughout the Western Ghats well before the pre-colonial period, the British in the late 19th century AD by implementing the Charter of Indian Forest in 1855 did replace the community management by state forest management on these lands. The impact of this change in the management was so dramatic and irreversible. In *Uttara Kannada* district, the forest department reserved the extraction and collection of the non-wood forest produce only to the introduced contractors (Wingate 1988). In Shimoga, the management of the *kans* was taken away from the local people and later declared as the land for cultivation of coffee (Brandis and Grant 1868). Again in both these districts, several of the *kans* were handed over to the Areca growers as well as added to the category of the open access, which were declared as the 'minor forest'. These accelerated the massive destruction of *kans* and sacred groves. See Figure 2.1 for the map of Western Ghats and the study site.

2.2 SRINGERI VILLAGE ECOSYSTEM

The entire Sringeri taluk is mainly covered by the wet evergreen forest, and is considered as a village ecosystem, where people and nature exist harmoniously 75 percent of the total geographical area is under evergreen forests. The total revenue statistics of Sringeri taluk is given in the Table 2.1 (Courtsey: Farmer's association, Sringeri, 2004 survey). Most of the people in Sringeri are dependant on forest for their basic needs, such as fuel wood, leaf litter and green foliages for the organic compost etc.

2.2.1 Location and Extent

Sringeri- the smallest taluk of Chikmagalur district in Karnataka state, is named after Rishyashruna, a sage who is said to have performed penance at one of the hillocks

situated near Sringeri at Kigga. Sringeri, with a total geographical area of 442.32 km² locates between 13° 15' - 13° 36' N and 75° 04' - 75° 22' E, in the eastern descent of the Western Ghats to Deccan plateau near Agumbe, and is surrounded by the gorgeous cliffs of the Western ghats. Sringeri taluk has two large State Reserve forest fragments, Narasimhaparvata and Tungabadra, and recently some of these forests also have been declared as the part of the adjacent Kudremukh National Park. Sringeri is blessed by Tunga, a perennial river that originates 40 km south, at Gangamoola in Kudremukh National Park. The altitude ranges from 625 – 1450 m, with an average altitude of 750 msl.

After the Karnataka State formation in 1959, Sringeri was declared as a taluk with 49 villages. Sringeri boasts of a world famous monastery established by Shankaracharya in 12th century AD.

Unlike *Uttara Kannada*, Chikmagalur district was least exploited and influenced by the wood based industries set up by the British colonialists, due to its undulating terrain. However, the Sringeri Mutt encouraged the conversion of forests into Areca gardens (Kamath 1981). Further, the local farmers encroached upon the adjacent minor forests surrounding their Areca orchards in the form of individual *Soppinabetta* (see later for the description of *Soppinabetta*). At present, Sringeri landscape chiefly consists of Areca Orchards, Acacia plantations, minor forests, *Soppinabetta* and cultivated rice paddy fields with a good proportion of revenue forest forming at least 55 % of forest cover. But, the increased market for Areca and Ginger, is giving way to rapid transformation of rice paddy lands into Areca orchards in Sringeri.

2.2.2 Climate and Physiography in Sringeri

The seasonality of Sringeri is mainly dependant on the southwestern monsoon, which usually hit Sringeri by June every year, and continues till October. However, sometimes the monsoon continues till December with some winter shower. Although, Sringeri enjoys the northeast monsoon during summer, the downpour usually is restricted to a maximum of one week. The annual rainfall generally varies between 3500 – 5000 mm/year. The dry months in Sringeri is between December – May, and the mean daily maximum temperature at Sringeri varies between 22.5° C (July) – 35° C (April), and the

mean daily minimum temperature varies between 13° C (January) – 19° C in May (Data courtesy, Sringeri taluk office). Soils of the Sringeri are classified as Inceptisols and Ultisols (Bourgeon 1989).

Table 2.1. Revenue statistics (total) of Sringeri taluk for the year 2004 (courtesy: Farmers' association, Sringeri taluk).

	Area (in Acres)	% Of total area	% Of total cult. area
Total Area	1,10,178		
Tot cultivated area	14,639.46	13.29	
Landuse types			
Dry land	915.16	0.83	6.25
Thari	10123.03	9.19	69.15
Bagayat	3017	2.74	20.61
Plantations	584.27	0.53	3.99

The monthly rainfall data during the study period, 2003-2004 at three different locations in Sringeri shows that rainfall was highest during 2004. The maximum total rainfall is measured at Kerekatte (6045.5mm), which locates 20 km south of Sringeri, and inside Kudremukh NP. In 2003, again Kerekatte recorded the maximum rainfall in Sringeri taluk (5459.7 mm) (See Figure 2.2 and 2.3). However, most of my study sites are away from Kerekatte, and for 5 of my study sites, rainfall from Kigga is applicable and for another 10 study sites the rainfall of Sringeri is applicable. Six other study sites are > 13 km away from Sringeri town towards North and usually get the rainfall from Kigga and Agumbe regimes. The rainfall recorded in Sringeri till July 2005, is 4,785 mm.

2.2.3 Vegetation

The forest in Sringeri is classified as Tropical Evergreen, and both wet and dry evergreen forests are seen in the Sringeri taluk. The state forests in Narasimhaparvata and Thungbadra, are wet evergreen, and comprised mainly of the evergreen tree species. The pioneer tree species (30 m and above) in these forests are *Poeciloneuron indicum* Bedd., *Elaeocarpus tuberculatus* Roxb., *Bischofia javanica* Bl., *Persea macrantha* (Ness) Kosterm., *Lophopetalum wightianum* Arn., *Calophyllum apetalum* Wild., *Hopea canarensis* Hole etc. The understory (< 10 m in height) is dominated by *Dichapetalum gelonioides* (Roxb.) Engl., *Agrostistachys indica* Dalz., *Psychotria* spp., *Cinnamomum sulphuratum* Nees etc. (Nayak *et al.* 2000).

In Sringeri town and surrounding areas, the forest is mainly comprised of semi-evergreen species, and the tree canopy is dominated by *Chrysophyllum lanceolatum* (Bl.) DS., *Canarium strictum* Roxb., *Syzygium* spp., *Diospyros* spp., *Hopea parviflora* Bedd., *Holigarna* spp. etc., and the understory is dominated by *Leea* spp., *Meogyne pennosa* (Dalz.) Sincl., *Arenga wightii* Griff., *Psychotria* spp. etc. However, most of the revenue forests in Sringeri is dominated by a liana species, *Entada pursaetha* DC.

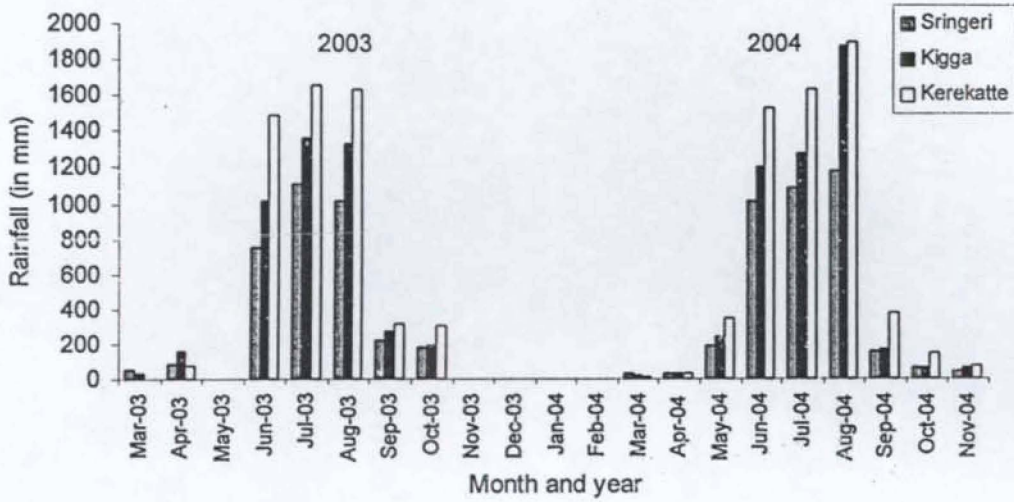


Figure 2.2 Monthly rainfall at three different locations (Sringeri, Kigga, Kerekatte) in Sringeri taluk during study period, 2003 – 2004

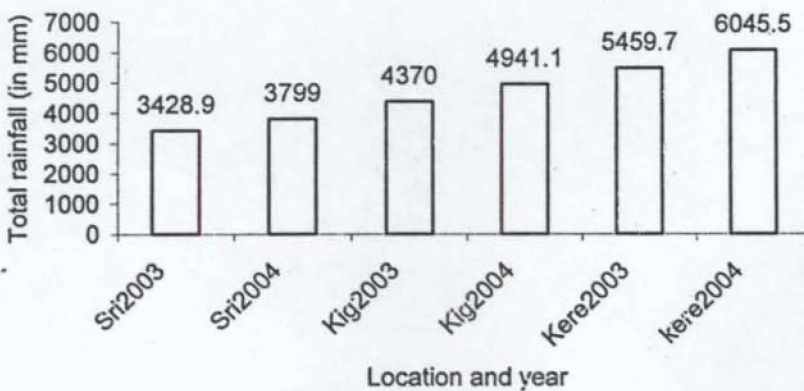


Figure 2.3 Total rainfall at three locations in Sringeri taluk during study period 2003 – 2004 (Sri = Sringeri, Kig = Kigga, Kere = Kerekatte)

2.2.4 Land use types and forest management in Sringeri

Forests in Sringeri mainly follow two management practices, namely, state forest management and community forest management. Apart from these natural forests, the demand for social forestry is also on the increase in Sringeri. The social forestry is an afforestation program carried out by the Karnataka Forest Department (KFD) by planting the saplings of exotic plants like *Acacia auriculiformis* and *Eucalyptus* sp. in the dryland. The major land use types of Sringeri taluk are explained below. A subset of land use types of Sringeri is given in Plate 1.

1. Reserve forest

Most of the Malnaad forests are under this category and Karnataka Forest Department (KFD) is the ultimate custodian, and exerts maximum control over this forest. However, Sringeri has a small proportion of reserve forest, and as mentioned above, extends upto Narasimhaparvata and Tungabadra. Limited collection of fuel wood and fodder by the local people is permitted, but no logging or felling of the trees is allowed. Forest department annually call for the tenders to give the rights to extract, and trade the Non Timber Forest Products (NTFP). But these privileges to the community can be withdrawn at any time, when any part of these lands are declared as the forest nurseries for the timber production or as Wildlife- sanctuaries and National Parks. Most of these forests are seen in the periphery of the WLSs and NPs or in large villages or as *kans* and part of the Sacred groves. In Sringeri taluk, as per the revenue statistics in 1998, 45.80 % of the land area is classified as the RFs (Courtsey, Sringeri taluk Office).

2. Minor Forest

These are the forests assigned to each village in the ratio of 1 ha for every head of cattle and are the public access land for their daily needs like fuel wood, fodder, leaf mulch and poles for fences etc. But, these proportions are not being followed strictly in every village (Masur 1918), since the villagers have neither exclusive use, nor the formal role in the management. After decades of unprecedented use of these forests, most of these forests are converted in to degraded scrublands. Although, it is a categorized forestland in Sringeri,

almost all of them are being converted into the Acacia plantations in the recent past. 14.09 percent of the total geographical area of Sringeri area is comes under this category.

3. *Soppinabetta forests*

Soppinabetta literally means the foliage ^{Hills} forests (*Soppu* = foliage, *betta* = ^{Hills} forests). These are the earmarked minor forests by the state, and assigned to the local Areca and Coffee farmers, which allows them to use these forests for their organic subsistence in the form of leaf litter and green foliages for their paddy fields and Areca orchards. This practice dates back to at least 4th Century AD (Gadgil and Chandran 1988). It was first introduced in *Uttara Kannada* district, where about eight times of the minor forest areas are now allocated as the Soppina betta lands. Later it was expanded to other *Malnaad* districts like Shimoga, Chikmagalur and Dakshina Kanna districts of the Western Ghats. The cash crops like Areca requiring organic subsistence from the *Soppinabetta* was taxed at a higher rate than the paddy, and the farmer's privilege were regularized in 1924 (Kamath 1985). Although, these farmer managed forestlands are under severe pressure from various anthropogenic pressures, the status of *Soppinabetta* is relatively stable and safe due to its undulating terrain and sparse population (< 100 individuals km⁻²). Approximately, 20.52 % of the total land area is classified into *Soppinabetts* lands in Sringeri taluk. The *Soppinabetta* forests, their vegetation structure, and their importance to the local community are explained in the next section.

4. *Cultivated Lands*

Three kinds of cultivated lands are seen in Sringeri taluk, *Thari*, *Bagayat*, and plantations. Food grains, and other perennial crops dominate *Thari cultivation*; while *Bagayat* is horticultural cultivation and is dominated by Areca orchards, which is a complex horticulture system that has evolved here centuries back. Areca orchards in most villages in Sringeri are having three strata, where *Areca catechu* (betel nut) is the top canopy with a mid canopy of the heads of Banana (*Musa sapientum*), Orange and Citrus plants; in some Orchards, Cocoa cultivation is also found to be practiced. Coffee (*Coffea arabica* and *Coffea robusta*) and Cardamom (*Elettaria cardamom*) plants are the understory cultivation in these orchards. However, the extent of monoculture coffee plantations in Sringeri is very less, and restricted to large landlords. The black pepper

(*Piper nigrum*) and betel-leaf (*Piper betle*) are the common and economical vines seen in these orchards. Very recently, farmers have started cultivating Vanilla in these orchards, which are mainly restricted towards the shady descents of the forest areas. 2.74 % of the total land area in Sringeri is classified as *Bagayat*.

5. *Acacia plantations*

These are the major tree based monoculture plantations commonly seen in Sringeri area of Chikmagalur district, as part of the current afforestation programs undertaken by the Karnataka Forest Department (KFD), and is named as Social forestry. They plant the saplings of wattle in the degraded minor forests, and grazing lands, which in another 5 years become full-grown plantations. Apart from KFD, several individual farmers also have started these practices by planting other timber-valued plants like *Acacia mangium* and Eucalyptus in their holdings as part of Social forestry. Most of the KFD operated plantations are auctioned to major paper and pulp factories in Mysore and Kerala. However, forest departments claim it as a Joint Forest Management (JFM) initiative with support from the World Bank (Personal communication with Social forestry department, KFD, Sringeri). At present, 0.56 percent of total land area is *Acacia* plantations, and belongs to the KFD.

2.3 SOPPINABETTA FORESTS OF SRINGERI

As described above, *Soppinabetta* lands are the uncultivated forestlands that are allocated to each farmer, who holds a good proportion of Areca lands to meet their need for the organic compost in the form of dung mulch.

2.3.1 *History of Soppinabetta*

The allocation of *Soppinabetta* forests to the local Areca growers dates back to the 1890s in *Malnaad* region of Sringeri taluk. The ratio of allocation of *Soppinabetta* land to the Areca land in *Uttara Kannada* was 9: 1 and now it is reduced to 8: 1 per farmer (Mani 1985). However, this ratio is still found to be high, and is identified as the major reason for the fast degradation of *Soppinabetta* forests of *Uttara Kannada*. However, in Sringeri the latest data shows that the allocation of *Soppinabetta* lands to Areca holders is 2.5: 1 per landlord. A study by Nayak *et al.* (2000) reveals that a 2: 1 allocation would be better for the well being of the *Soppinabetta* lands in Sringeri. The study also found that the

Management value of *Soppinabetta* lands increase with the economic stability of the farmer, and not with the increasing proportion of *Soppinabetta* lands.

2.3.2 Importance of *Soppinabetta* lands to local community

Soppinabetta lands in the Western Ghats of Karnataka state is a backbone of the rural economy in *Malnaad* region, which helps the farmers in several ways. Firstly, almost all the households depend upon forest vegetation for meeting their fuel wood as well as to certain extent for the structural materials for building fences, livestock sheds etc. Secondly as most of this region is high rainfall area, the rice paddy lands as well as Areca orchards require continuous supply of organic manure to enrich the leached soil. This organic manure comes from the leaf litter, and green foliages of these forests. The leaf litter extraction is carried out during the summer season for 4 months and green foliage pruning during wet season for 3-4 months every year.

Considering overall composition of *Soppinabetta* forests in Sringeri, the major species that farmer prefers for the leaf litter and green foliages are *Aporosa lindleyana*, *Hopea ponga*, *Hopea parviflora*, *Memecylon umbellatum*, *Syzigium cuminii*, *Syzigium caryophyllatum*, *Lophopetalum wightianum*, *Litsea floribunda*, *Poeciloneuron indicum* etc. Most of these *Soppinabetta* forests are different from the other revenue and reserve forests in Sringeri compositionally. Apart from this, local community also depend on these minor forests for NTFPs like fruits of *Garcinia gummigutta*, seeds and resin of *Canarium indicum*, which do have some economic value in the market, and also to a certain extent on honey extraction too. Most of the people also collect a number of wild plants for the curries and their daily needs. As part of Joint Forest Management (JFM), some farmers also have started fencing and planting *Piper nigrum* in their SB lands.

The vegetation studies (Nayak *et al.* 2000) have shown that the floral richness of these lands though varies structurally as well as compositionally, are equal to that of undisturbed primary forest of Sringeri. Unlike *Uttara Kannada*, the status of these forests appear to be good, and it is found that at least the large landlords are preserving these forests from further immediate degradation and encroachment.

Influence of different land use corridors on insect pests and insect natural enemy guilds of paddy agro-ecosystems

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A thesis
Submitted for the degree of
Doctor of Philosophy
In the Faculty of Sciences



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Chapter 3

FLORAL AND ARTHROPOD COMMUNITY STRUCTURE OF RICE PADDY AGRO-LANDSCAPES OF SRINGERI VILLAGE ECOSYSTEM

3.1 INTRODUCTION

Rice (*Oryza sativa* Linn.) is served as the staple food for over half of the world's populations, and is grown worldwide in over 124 million hectares (Barrion and Litsinger 1994). It feeds nearly 65 % of total population of India, and also a good proportion of people in several other Asian countries. India is one of the original centers of rice cultivation. The god Shiva called rice as *vrihi* in Sanskrit. The Asian rice plant is considered to have originated in the Assam – Yunnan area, and to have spread during the last few thousand years over a wide area, which extends from 51° N – 35° S (Kisimoto 1991). However, the major portion of the production comes from the geographical area between 43° N – 39° S, and over 90 % of the rice production and consumption happens in China and India along with other south and Southeast Asian countries. India ranks second in the production, which is next to China (FAO 2004), the largest producer of the world. Rice cultivation is the principal activity, and source of income for millions of households around the globe, and several countries of Asia and Africa are highly dependent on rice as a source of foreign exchange earnings and government revenue (FAO 2004). Rice is the central part of many cultures, and folklore activities of many

countries are related to the rice cultivation. The rice production of India is approximately 86 million tones, which constitutes 40 % of the total food grain production (Rai *et al.* 2000). Rice cultivation is carried out at various elevations from sea level up to 2000m, and is called as lowland, mid land and upland cultivation.

In Karnataka rice is cultivated in nearly 1.16 million hectare of the geographical area (Anon. 1992) during two major seasons: *Kharif* (84.14% of the production) and summer (11.67 %) (Anon. 1987). Although, a wide range of traditional cultivar types, such as *Dappabatha*, *Padmarekhe*, *Abhilasha* were used by Sringeri farmers, the most popular one is a hybrid seed variety called IET.

3.1.1 Biodiversity of Rice paddy agro-ecosystems

The invertebrate and plant community structure of any of the terrestrial ecosystems, are related. In monoculture systems, like rice agro-ecosystems, the environment, cultivar types, cropping pattern, and cultivation practices influence these communities (Heong *et al.* 1991), apart from the vegetational diversity within, and surrounding area (Landis *et al.* 2000).

Rice agro-ecosystems, although an artificial land use type, are considered as extensions of marshy areas, and some authors consider them as wetland habitats (Odum 1963). Though most of the rice paddy agro-ecosystems are monocultures, it provides a good environment for a variety of flora (Moody 1989, Chandrasena 1988), invertebrate and vertebrate fauna (Grist and Lever 1969), and also for birds (Ali and Ripley 1968-1974). Chatterjee and Dutta (1980) have recorded crabs *Paratelphusa hydrodromus* Herbst and *P. spinigera* Wood-Mason as common rice pests in West Bengal, which feeds on rice seedlings at nursery stage and also on the newly transplanted saplings, by cutting the basal regions of plants. Subramanya (1987) has recorded 81 species of birds in the rice paddy fields in Bangalore district. Out of this 61.17 % of the bird species visited the paddy fields, only for feeding.

Grist & Leaver (1969) has recorded more than 700 species of ~~the~~ insects falling under 9 orders and 40 families from rice paddy agro – ecosystems. They also have reported 20 species of rodents, 65 species of birds, and 10 species of fishes that make use of the cultivated rice paddy field for a number of purposes. However, only 20 species of

serious

insects were reported as ~~severe~~ pests of rice all over the world. Heckman (1979) recorded 589 species of biota, comprising of 162 species of plants, and 422 species of animals including insects. Barrion & Litsinger (1994) have identified nearly 900 species of arthropods (insects and spiders alone) from the irrigated rice paddy agro-ecosystems. Rai *et al.* (2000) have provided a checklist of 368 species of coleopteran insects associated with the rice paddy agro-ecosystems, which comprises 191 genera, and 26 families. However they have identified only fifty species, which do have a major or minor economic significance in the rice agro – ecosystems as pests. They have reported a good proportion of species from four major coleopteran families such as Chrysomelidae, Coccinellidae, Curculionidae, and Scarabaeidae. The checklist has provided the feeding guilds of each species and family, this checklist has been referred to assign the feeding guild of each family of Order Coleoptera during guild analysis in this study. Settle *et al.* (1996) catalogued 765 species of insects and spiders from the Indonesian lowland rice paddy fields.

Arthropod predators and parasitoids are among the most important and abundant functional guilds of rice paddy fields of tropical south and Southeast Asia. Natural biological control in irrigated rice fields, during early stages is mainly attributed to spiders. This is because, a good proportion of the predatory arthropods in rice agro-ecosystems comprises of three guilds of spiders: orb-weaving spiders, hunting spiders, and space web spiders. Major families of rice ecosystem spiders are Araneidae, Tetragnathidae (Orb-weaving), Lycosidae, Salticidae (Hunters), Theridiidae, and Linyphiidae (Space web spiders) (Barrion and Litsinger 1995). Of these, orb-weaving spiders were identified as the most abundant spiders in the cropping season (Barrion and Litsinger 1995, Sigsgaard 2000). Heong *et al.* (1992), have reported that a Lycosid spider, *Pardosa pseudoannulata*, alone represents ~ 55 % of the total spider species' of the Philippine rice agro-ecosystems. Several workers (Barrion and Litsinger 1984, Shepard *et al.* 1987, Rubia *et al.* 1990) have reported the potential role of *P. pseudoannulata* as a predator of major rice pests like leaf and plant hoppers, whirl maggot flies, leaf-folders (*Cnaphalocrocis medinalis*), case worm (*Nymphula depunctalis*) and stem borers (*Shoebotus* spp). The role of spiders in controlling several

Scorphaenidae?

of the major rice paddy pests is recorded by several researchers (Kenmore *et al.* 1984, Shepard *et al.* 1987, Ooi and Shepard 1994).

In India, Narasimharao *et al.* (1978), Thomas *et al.* (1979), Ghode *et al.* (1985), Gupta *et al.* (1986), Bhardwaj and Pawar (1987), Bhathal *et al.* (1992), Ansari and Pawar (1992), Venkateshalu (1996), and Reddy (2000) have enriched our knowledge on spider fauna of rice paddy agro-ecosystems. Among these, Ansari and Pawar (1992), Venkateshalu (1996), and Reddy (2000) have dealt with the spider population of rice ecosystems of Karnataka state in India. Ansari and Pawar (1992) have given a detailed checklist of spiders seen in three kinds of rice paddy lands (upland, midland, and lowland). Nevertheless, with few exceptions, most of the studies have found that Lycosidae (at ground level), and Tetragnathidae (at paddy canopy level) were the dominant spider families of this wetland ecosystem. Venkateshalu (1996) and Reddy (2000) have recorded 23 and 20 species of spiders respectively from the rice paddy agro-ecosystems of Mandya and Bangalore districts of Karnataka State.

Heong *et al.* (1991) in their study on rice paddy agro-ecosystems of the Philippine cultivated rice paddy agro – ecosystems have recorded 212 species of arthropods, which include phytophages, predators & parasitoids, scavengers, and tourists. However, nearly 50 % of the population was contributed by phytophages. They also have mentioned that relative to predatory arthropods (56%), the proportion of the parasitic wasps (4%) were negligible in the rice paddy agro-ecosystems of Philippines. Spiders alone have contributed a good proportion of the predatory guild. 40 families of parasitoids from three orders, Hymenoptera, Diptera and Strepsiptera have been listed; but Mymarids, especially *Gonatocerus* spp, dominated 55 – 87 % of the total parasitoid population.

Shepard & Ooi (1991) discussed major parasitoids and predatory species of rice ecosystems, and emphasized that their conservation is paramount to the success of any IPM in rice agro-ecosystems. Rather than giving a mere checklist of the natural enemies of rice paddy agro-ecosystems, very few studies have tried to trace out the host ranges, and their mode of actions. The notable studies on the role of predatory arthropods in rice paddy agro – ecosystems are Shepard *et al.* (1987), van Vreden & Latif (1986), Yasumatsu *et al.* (1982), and Barrion & Litsinger (1984). Studies of Nickel (1964), Chiu

(1979), Greathead (1983) and Otake (1997) were the major inventory works of parasitic wasps of major rice pests.

The rice paddy lands harbors a rich floral community, in three different habitats of rice paddy lands: the field proper, the bunds, and small ditches and water canals. The flora of field proper is seen at two stages: fallows and cultivated paddy fields, which mainly comprises of macrophytes (broad leaved plants). Moody (1989), enumerated 1800 species of plants (macro and microphytes) from the paddy fields of south and Southeast Asia. Velmurugu (1980) documented 80 common species of plants in the rice paddy lands. Weerakoon and Gunewardena (1983) recorded 134 species of weeds from rice paddy fields of Sri Lanka.

Pests are the other major functional guild of rice paddy agro – ecosystems. Although abundant in number, the pest species richness is comparatively low in this wetland ecosystem. If stem borers (Lepidoptera: Pyralidae) were the only pests that had caused a considerable amount of damage to the rice paddy till 1960s, the green revolution in the sixties and seventies led to the emergence of several new pests in rice growing countries. Several minor pests, such as leaf and plant hoppers, have attained the status of major pests during this period. In the history of rice cultivation, the most important and highly *problematic* tragedy was the up gradation of *Nilaparvata lugens* Stål, from minor to major pest status (Kenmore 1984, Reissig *et al.* 1986), in the aftermath of green revolution. Cohen *et al.* (1994), though had reported more than 645 taxa of animals (arthropods, nematodes, viruses, fungal pathogens, and vertebrates) in Philippines rice fields, but only 25 species, which were enlisted in the paper, were identified as the major and minor pests of rice paddy.

3.1.2 Objectives of the study

The broad objective of this study is to investigate and document arthropod, floral community structure, and soil characteristics of Sringeri rice paddy agro – landscapes. The study also attempts to record major pests and arthropod natural enemy populations of rice paddy agro – ecosystems of Sringeri.

3.2 METHODS

3.2.1 STUDY LOCATIONS AND CODES USED TO SPECIFY STUDY POINTS

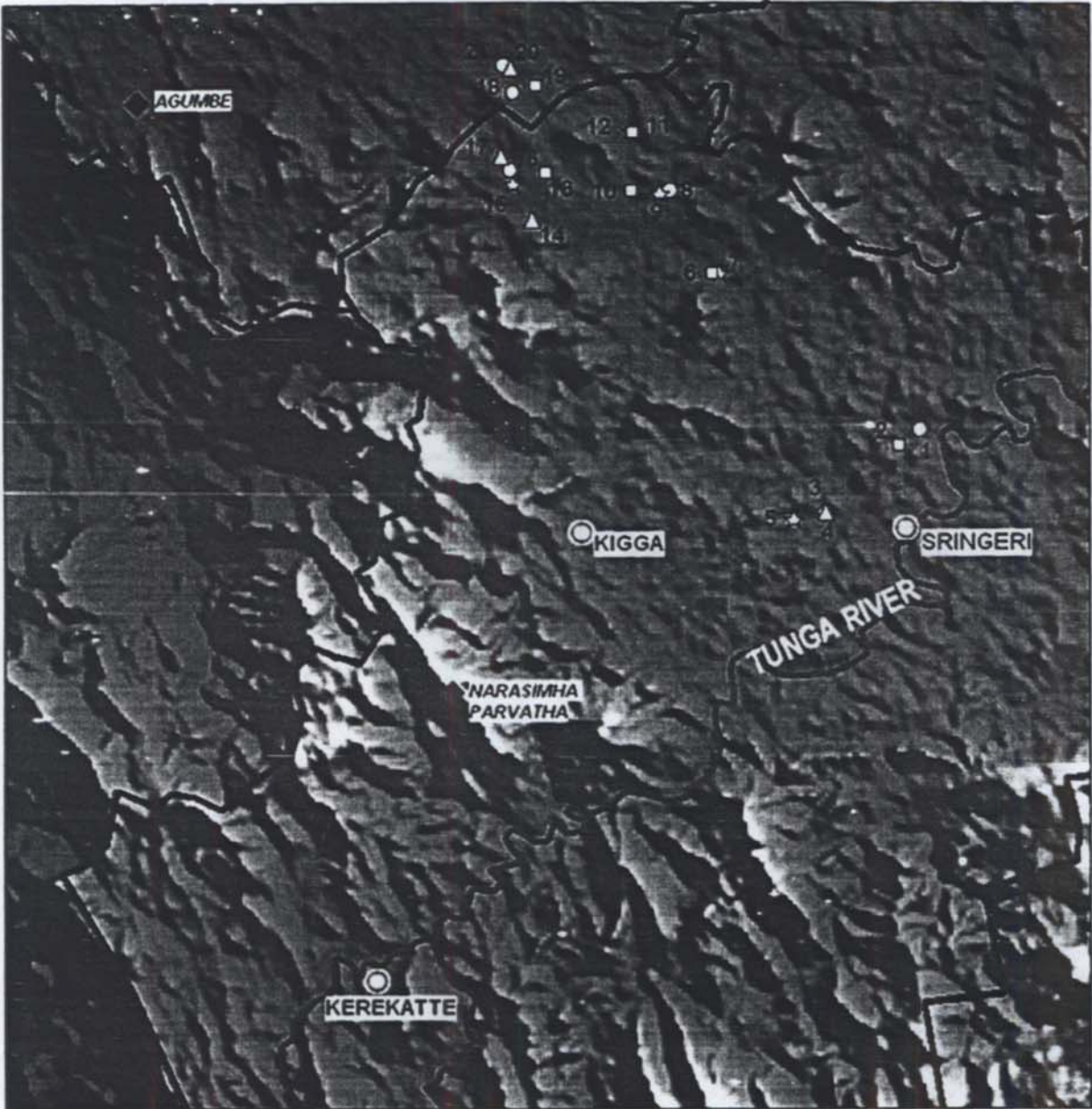
The study was carried out in rice paddy agro – landscapes of Sringeri and Thirthahalli taluks of Chikmagalur and Shimoga districts of Karnataka State during 2003-2004. The study site description is available in Chapter 2 (see Figure 2.1). Two base stations, one in Sringeri, and another at the boundary between Thirthahalli and Sringeri taluks were established. The specific study locations are mapped, and are available in Figure 3.1, and geographical position, and altitude of each study location is given in Table 3.1.

21 study locations as shown in the map (Figure 3.1) were selected for the present study. See Plate 2 for the photographs of four kinds of rice paddy agro-landscapes of Sringeri. The decision on agronomic practices, such as cultivar selection, dates of transplantation, irrigation, pesticide and fertilizer use, manuring, harvesting etc. were left to the farmer. Study sites were selected purely based on similarities in timing of farming practices with the neighboring (non-experimental) paddy fields.

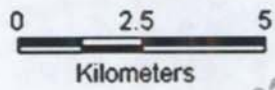
The codes used in this study to name the 21 study locations are described below. The first two characters of the selected study locations explain the corridor habitat or land use type adjacent to rice paddy field, and the following word is either the name of the village or the farmer's name (Enlisted in Table 3.1). For instance, AR Sringeri explains that paddy field adjacent to Areca Orchard is the selected site in Sringeri; and SB Nagendra means, Paddy field is margined by *Soppinabetta* forests, and is owned by the farmer Nagendra.

Table 3.1. Geographical position, altitude, and village of each study location; see map for more specifications

Sl.No.	Village name	Location (Ref map)	Geographical position				Altitude (m)
			Latitude		Longitude		
1	Honnavalli	AR Sringeri	13°	26.301N	75°	15.386E	633
2	Honnavalli	SB Nagendra	13°	26.103N	75°	15.096E	651
3	Uluvalli	AC Kigga	13°	25.26N	75°	14.199E	642
4	Uluvalli	AR Vatsa	13°	25.26N	75°	14.199E	642
5	Uluvalli	DS Hegde	13°	25.172N	75°	13.797E	657
6	Marikebel	SB Mbelu	13°	28.277N	75°	12.878E	639
7	Marikebel	DS Mbelu	13°	28.277N	75°	12.878E	639
8	Kumbarakodu	AR Sathish	13°	22.415N	75°	12.288E	636
9	Kumbarakodu	DS Nar	13°	29.293N	75°	12.165E	633



- △ ACACIA - PADDY
- ARECA - PADDY
- ☆ DEGRADED SCRUB - PADDY
- SOPPINABETTA - PADDY



You should have used a colour map. The sites are not at all clear.

Figure 3.1. Map showing study locations

10	Kumbarakodu	SB Kruthi	13°	29.338N	75°	11.811E	628
11	Begar	SB Achar	13°	30.084N	75°	11.814E	622
12	Begar	DS Achar	13°	30.084N	75°	11.814E	622
13	Gandugatte	SB Manju	13°	29.571N	75°	10.767E	636
14	Kalige	AC Gopal	13°	28.964N	75°	10.608E	639
15	Kotte	DS Kotte	13°	29.524N	75°	10.368E	636
16	Kotte	AR Kotte	13°	29.672N	75°	10.33E	636
17	Kotte	AC Kotte	13°	29.777N	75°	10.219E	637
18	Hosahalli	AR Pai	13°	30.633N	75°	10.463E	634
19	Hosahalli	SB HS	13°	30.664N	75°	10.645E	627
20	Balehalli	AC Huappa	13°	30.92N	75°	10.284E	630
21	Balehalli	AR Devappa	13°	30.953N	75°	10.26E	636

3.2.2 ARTHROPOD SAMPLING

Based on study objectives, different sampling practices were adapted to sample arthropods. The data generated on species abundance and richness was mainly used to analyze data. The sampling was conducted for two different stages of paddy fields, 1) from fallows (Off-season), and 2) from paddy fields (crop season).

3.2.2.1 During Off-season

Four sampling procedures were followed to sample arthropods from fallows in uncultivated season: pitfall traps, all out search method, sweeping, and Malaise sampling. The details of transect and sampling technique of each method is described below.

Transect laying and Pitfall (PF) sampling

A single line transect of 100 m length was laid from the edge of each paddy field towards the center in each of the 21 study sites. Two quadrates of 10 X 10 m, one at 50th meter, and other at center of the paddy fields, which is approximately 100 m away from the edge, were laid in each transect. Another quadrate of equal dimension was laid in the adjacent experimental corridor type, 10 m away from the edge of paddy field.

Pitfall traps (Southwood 1978) are the widely used sampling method to study the ground dwelling arthropods in all terrestrial habitats. In ecological research, it is mainly used to study the population size, and activity abundance of ground dwelling arthropods, which are set as the indicator species of ecosystem processes and functions. In taxonomy research, it was first introduced in ground beetle (Coleoptera: Carabidae) studies, and

now it is considered as the best method to sample almost all ground dwelling arthropods. Pitfalls can be glass or plastic bottles with or without artificial shade, baits, or preservatives. These traps are sunk into pits in the ground. The mouth of the trap will be continuous with the ground.

In this study, 500 ml transparent plastic jars of 10 cm height, and 6 cm diameter were used as the pitfall traps. 30 ml 10% Isopropyl alcohol (IPA) was the preservative in each pitfall trap, and all traps were laid for 5 continuous days and taken out on the 6th day. Each pitfall trap was covered with a plastic shade, which was erected on four stumps at a height of 8 cm, to prevent the inflow of rainwater, and to reduce evaporation rate of the preservative. Maximum care was taken while attending to the pitfall traps on every alternate day. The stolen and animal interfered traps were replaced with a new trap, but kept 1 m away from the original position to nullify the disturbance. Maximum care was also taken to sample all the study sites together to reduce the sampling artifacts. Five pitfall traps were laid in each quadrat. Pitfall traps were arranged in such a way that four are in the corners and one at the center of each quadrat.

All out Search Method (VC)

Three quadrates of 0.5 X 0.5 m, two in paddy fields at 50th and 100th m, and one inside adjacent land use type, were laid. All soil dwelling arthropods in these quadrates were captured either by hand picking or by using a fine brush. A period of about 15 min was spent in each quadrat. All arthropods were preserved in 70 % ethanol.

Sweeping (SW)

Sweep samples were taken both from fallows and adjacent uncultivated corridor habitats. Only ground flora and shrubs were swept in the corridors. Five sweeps- each consisting of nine full cycles of "figure 8" sweep (Kogan and Pitre 1980)- were made in each plot (inside corridor, at 50th meter and at 100th meter inside fallow). The sampling were made perpendicular to the line transect at 50 and 100 m inside the fallows, and 5 m away from the edge inside the experimental land use type. All arthropods caught in the sweep net were sucked by an aspirator and preserved in 70 % Ethanol.

Malaise traps (Mal)

Originally invented by Dr. R. Malaise, this trap makes use of the negatively geotactic and positively phototactic behaviour of insects. The Malaise trap model used was a bi-

directional Townes style with 203 cm front height, 112 cm back height, and 122 cm wide by 183 cm long (Townes 1972). This tent like device catches active insects by chance as they fly into the sides of the trap, they crawl upwards to the roof (negatively geotactic behaviour) where they enter into the collecting bottle (usually situated in the direction of sunlight), which contains 30 ml 70% ethanol.

Three malaise traps, one each at 50 and 100 m away from the edge, inside paddy field, and one 10 m away from the edge, inside the corridor were laid. All the three traps were laid for 24 hrs in each study site. The intercept of each trap faced the land use type, and the collection bottles always faced the rising sun. At a time, three plots of a single study site were sampled.

3.2.2.2 During Crop Season

Sweeping and Malaise sampling were done in the crop season too. Besides the above-described three plots, the part of the paddy fields at the interface between paddy fields and adjacent land use type were also swept, which is designated as 0 m. However, the number of sweeps in each plot was restricted to three, each with nine full cycles of “figure 8” sweep, in each plot. Sweeping in the paddy fields was done 30 days after transplanting (DAT) in rice paddy fields. Three plots in each study area were sampled using the Malaise trap continuously for 24 hours. Except insects from the order Lepidoptera, which were preserved dry, all other insects were preserved in 70 % Iso-propyl Alcohol till identification.

Apart from these systematic sampling, each of the paddy fields were visited frequently (opportunistic surveys) to estimate the pest - natural enemy build-ups, and also to study the behavior of pests and their natural enemies.

3.2.2.3 Sorting and Identification

The arthropods collected by pitfall traps were sorted out from the debris and soil using SINSORTER (Sinu 2005). All arthropods were sorted out and identified to family and then to morphospecies, except for pests, parasitoids and predators, which were identified to lower taxa wherever possible. Considering the crucial role of spiders in rice paddy agro – ecosystems; the spiders collected in the traps were identified, and the data used for further analysis.

3.2.3 VEGETATION SAMPLING

The standing vegetation inside paddy fields and adjacent land use corridors were sampled twice in the study period: during uncultivated season, where sampling was conducted only from fallows; and during crop season, where sampling was carried out both from the adjacent land use corridors as well as from the bunds of the paddy fields. The following attributes were studied in detail:

1. Species richness
2. Abundance
3. Percent grass cover (only during off season)

3.2.3.1 During Off-season

Three quadrates, each of 1 X 0.5 m were laid, one at 50th m and other at 100th meter inside the fallows. The number of species was first counted from each quadrate, which served as stand richness and number of individuals of respective species was noted down, which is used as another measure of diversity called stand density. Apart from this, the percentage grass cover of each quadrate was estimated by visual observation, as this greatly influences soil arthropod community.

3.2.3.2 During Crop season

Three quadrates of 1 X 0.5 m were laid in the bunds of paddy fields each at 50th and 100th m, and another three quadrates were laid in the corridor during crop season. Vegetation characteristics like, stand density (abundance), stand richness, fruiting plants, medicinally important plants etc. were noted down.

3.2.4 SOIL SAMPLING AND QUANTITATIVE ESTIMATION OF SOIL INGREDIENTS

Fifteen soil samples from each study site during fallow period were collected, i.e. five from corridor, five from PA50 and another five from PA100. Soil from 10 X 10 cm square and 5 cm depth were scooped out from each of this sampling point. The samples from each plot were mixed, and air-dried for 24 hours. 500 gm of dried soil was weighed out from each sub plot, and kept in cloth bags before being taken for analysis. Soil parameters like pH, Organic Carbon (Wet digestion method, Morgan 1956), Average Phosphorus (Av. P₂O₅ Kg / Acre) (Olsen's method, Olsen 1921), were estimated. Other

soil microclimate variables, such as soil temperature and soil humidity were also noted down at each sampling point during arthropod sampling in the off-season.

3.2.5. STATISTICAL ANALYSIS

Cumulative species richness and abundance were estimated for the arthropod and vegetational community of rice paddy agro – ecosystems, and considered as the measures of diversity.

3.2.5.1 *Species Accumulation Curve*

This is the widely used analysis tool to look into the completeness of sampling. Here cumulative observed species richness (Sobs), and expected true species richness (Chao 2) were plotted against the sampling effort. Observed and expected species richness was generated using EstimateS 7.0 program (Colwell 1997). 100 iterations were made before the estimation. Species accumulation curves were made for all four sampling methods, Pitfall, All out Search, Sweep, and Malaise for uncultivated season, where samples across study sites were pooled before analysis. Here, the sampling effort was the number of traps. The differences in the slope of the curve reflect the number of rare species in each sample; with a steep, positive slope indicating a higher proportion of singletons to doubletons in the sample (Colwell and Coddington 1994). The leveling off of the curve indicates that the sample more reliably represents the breadth of diversity in the species pool.

Species richness and abundance are considered as the measures of diversity. Species richness is the absolute number of species in a particular sample, and was the principal variable of interest. Observed species richness (Sobs), expected species richness (Chao 2), species abundance, and Species diversity (Shannon-Weiner index) were the other fundamental parameters of interest for the significance tests.

Non-parametric techniques are based on the distribution of individuals among species or of species among samples (Colwell and Coddington 1994). Chao 2 was used to estimate the true species richness of each sample. To prevent bias in calculations due to sample order, the number of observed species of each sample was randomized 100 times. Curves of observed species were also randomized for clarity in graphical representation.

Chao 2 estimates species richness including 'missed' species, using a form of extrapolation, depending on species occurrence, and takes the number of uniques (species that are seen only in one sample and not in others) and duplicates (species that are found only in two samples in the pooled data) into consideration to estimate the true and expected species richness. The equation is:

$$\text{Chao 2} = \text{Sobs} + (L^2 / 2M),$$

where Sobs is the number of species observed in all samples pooled, 'L' is the number of species seen only in one sample and not in any others (uniques) and 'M' is the number of species seen only in two samples (duplicates).

3.2.5.2 Comparison of arthropod and vegetation community between study sites

One-way ANOVA was used to compare both the community richness, and abundance between 21 study sites (P value to enter < 0.05).

3.3 RESULTS

3.3.1 ARTHROPOD COMMUNITY STRUCTURE OF SRINGERI RICE PADDY AGRO-LANDSCAPES

3.3.1.1 Summary

The one year field survey that includes arthropod sampling from rice paddy agro-landscapes of Sringeri in two seasons, off-season (fallows) and crop season, using various collection methods, brought out a total of 34,242 individuals of arthropods belonging to 814 species from 179 families and 18 orders. A good proportion of arthropods were collected from fallows during off-season, 24,843 individuals belonging to 612 species from all the four sampling methods. However, only 9,399 individuals were collected during crop season, using Sweeping and Malaise traps. Comparison of Malaise samples, where sampling effort in both the seasons were same, indicates that paddy fields in crop season attract more beneficial arthropods relative to off-season fallows. The Sweep samples that were not comparable between seasons due to difference in sampling efforts showed a predominance of species occurrence in fallows; however, parasitic wasps and dipterans were more abundant during the crop season. The count of species, family and orders of arthropods collected by each sampling method is given in the Table 3.2. An

attempt has been made to sort out and identify potential predators (spiders) and parasitoids (parasitic hymenopterans), wherever possible.

Table 3.3 summarizes the arthropod community diversity of each of the land use types, which include fallow and crop season paddy fields, and other adjacent land use corridors. (Please note that arthropod community diversity of paddy fields are not comparable with corridor types, paddy fields of both the seasons have two sub plots (PA 50 and PA100), against one sub plot of land use corridors; Diversity measures of arthropods of paddy fields of two seasons are also not comparable, in the off-season, arthropods were sampled using four sampling techniques, while only two sampling methods were used in the crop season. However, sweep and Malaise samples of paddy fields of fallow and crop season (see Table 3.2), where almost similar sampling efforts exist, are comparable.

Table 3.2 Number of individuals, species, families, and orders of arthropods collected using various sampling methods from fallow and crop season paddy agro-landscapes

	Method	Order	Family	Species	Individuals
Off-season	PF	16	100	361	17919
	Vaccum	12	66	210	3256
	Sweep -	10	97	255	2725
	Malaise -	10	59	109	943
	Total	16	150	612	24843
Crop season	Malaise	13	111	294	5654
	Sweep	12	76	171	3745
	Total	14	130	374	9399
Grand Total		18	179	814	34242

Table 3.3 Arthropod diversity measures of fallows, crop season paddy and other land use corridors

Season	Land use	Order	Family	Species	Individuals
Crop	SB	11	59	91	301
	DS	8	36	48	182
	AR	9	60	108	635
	AC	8	26	33	68
	Paddy	13	113	294	8213
Fallows (Off)	SB	15	90	213	3228
	DS	14	74	222	2052
	AR	13	85	198	2480
	AC	12	57	127	2911
	Paddy	16	124	451	14172

3.3.1.2 Arthropod community of Sringeri rice paddy agro – landscapes

Results indicate that the arthropod fauna during the two seasons in the rice paddy agro – landscapes, was dominated by Order Coleoptera with 39 families. This was followed by Order Diptera and Order Hymenoptera with 35 and 34 families, respectively. Order Araneae, comprising the spiders, was represented by 15 families (Figure 3.2).

Order Coleoptera was the most species rich with a total number of 252 species, which was followed by the Order Hymenoptera with 246 species. Nearly 30 % of this Order was represented by family Formicidae. However, the number of species collected from Order Diptera was very low (117 species) (Figure 3.3). Although, Diptera and Hymenoptera were represented by almost the same number of families, the considerable difference in the number of species between Order Hymenoptera and Diptera was mainly due to the presence of 76 species of ants collected in the off-season.

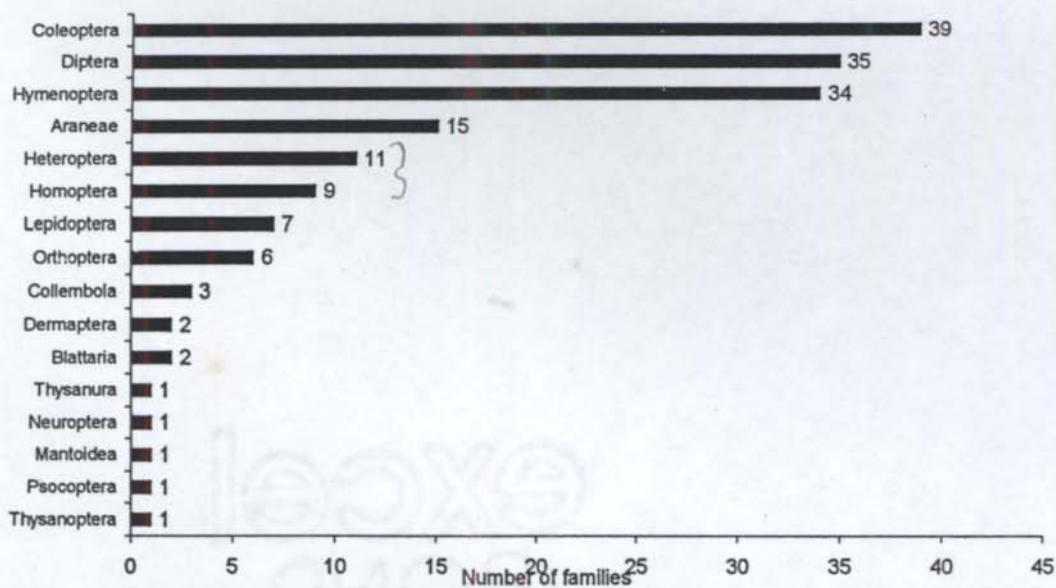


Figure 3.2 Number of arthropod families collected from various orders in off and crop season rice paddy agro-landscapes in Sringeri area

Although 252 species were recorded from the Order Coleoptera, 64 % of the species were represented jointly by 4 of the 38 Coleopteran families, viz. Carabidae (45 species), Scarabaeidae (35 species), Chrysomelidae (32 species) and Staphylinidae (29 species). All these families were well represented in the fallows rather than the crop season paddy.

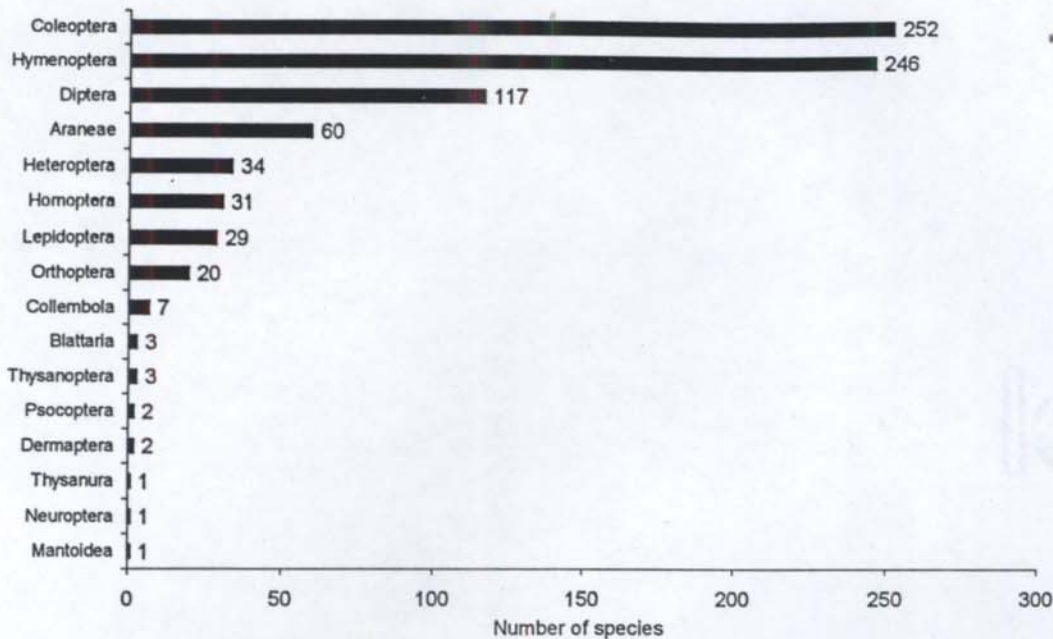


Figure 3.3. Number of morphospecies of arthropods collected from various orders in off and crop seasons from rice paddy agro-landscapes of Sringeri.

The results on the number of individuals of each Order in the combined off and Crop season data showed that Order Hymenoptera was the most abundant, with a total of 15,726 individuals from all families. However, nearly 90 % of this data composed of 14,148 individuals of 76 species of ants collected mainly by pitfall traps. Order Diptera with 6,834 individuals follows Order Hymenoptera, and almost 50 percent of the data was represented by the individuals of Chironomids (3486 individuals), which was collected mainly in the crop season, and is identified as a pest of paddy saplings. Although Order Coleoptera was family as well as species rich, it was relatively less abundant and only 4,726 individuals were collected (Figure 3.4).

why?
 What is a pest?
 Do chironomids satisfy
 the criterion of pest?

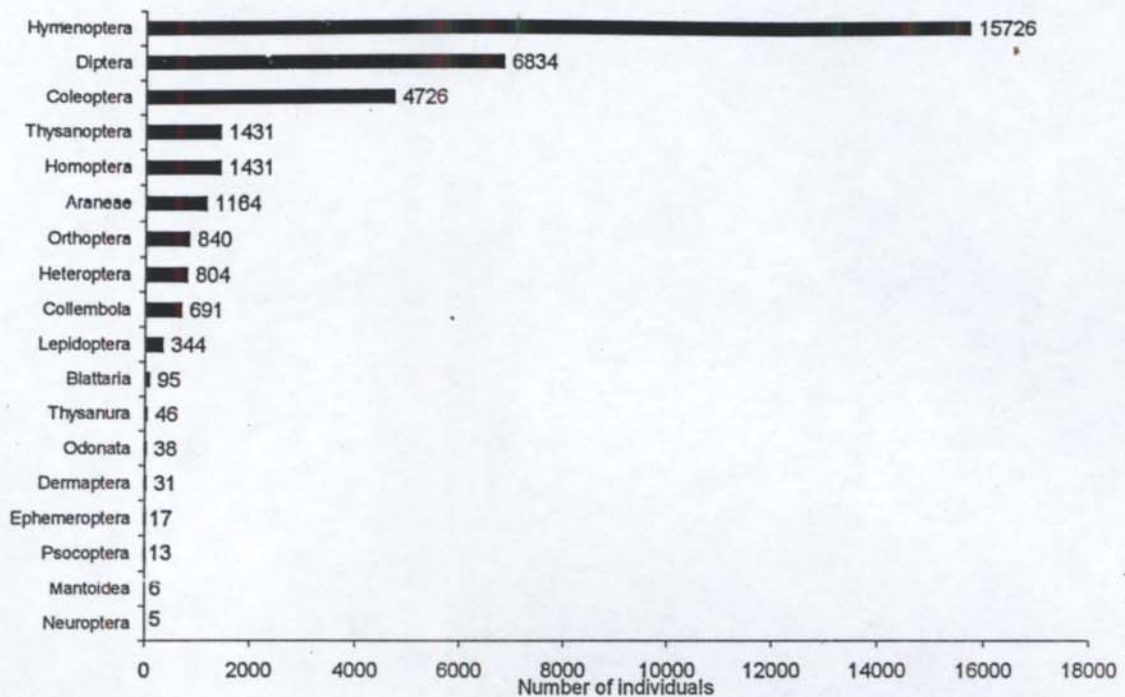


Figure 3.4. Number of individuals of arthropods collected on various methods from various orders in off and crop season rice paddy agro-landscapes in Sringeri.

A total of 629 arthropod species were collected from the paddy field in the entire study. Of this, 264 species (only 42%) were exclusively found in rice paddy fields, and were not encountered in any of the other adjacent land use corridors. However, most of these paddy specific species were rare, as the count of individuals of these species were less than 5. Meanwhile, 365 of the 629 species were found to occur in one or more of the four adjacent land use corridors, along with rice paddy lands. But, 236 species of arthropods found in paddy fields were represented by more than 10 individuals. Only 48 species shared all four land use corridor habitats along with paddy fields, which were considered as the highly generalist species. See Appendix I for the detailed list of species and abundance of each species.

Order Araneae

Order Araneae is well represented in the rice paddy agro – ecosystems of Sringeri landscape, mainly by families such as, Lycosidae, Oxyopidae, Salticidae, and Tetragnathidae.

The study yielded a total of 1,165 individuals from 59 species belonging to 15 families of spiders. Family Salticidae was the most species rich, followed by Gnaphosidae, Thomisidae and Lycosidae. 10 species were unidentified, and the families of these species were also not assigned. On abundance data, family Lycosidae was the most abundant, which was followed by Salticidae, Oxyopidae, and Tetragnathidae.

Family Lycosidae was most abundant both in the fallows as well as in the adjacent corridor types. Nearly 72 % of the abundance data of family Lycosidae was contributed by a single species, *Lycosa sp. 1*, which was followed by *Pardosa sumatrana* (16 %) and *Pardosa pseudoannulata* (10 %). More than 95 % of the Lycosids were captured by pitfall sampling. Although a total of 112 individuals of jumping spiders (Salticidae) were captured in the fallow period, nearly 62 % of the data was contributed by one species called, *Rhene flavigera*. The other 15 species of Salticidae jointly contributed merely 43 individuals during this period. Family Oxyopidae, was represented by 97 individuals of a single species, *Oxyopes sp. 2*, in the off-season.

Of the 56 spider species in the off-season, 30 terrestrial species were captured in pitfalls, and 29 species were captured by sweep samples, which were dominated by families, such as Oxyopidae, Thomisidae, and Theridiidae. Both the sampling methods were found to be efficient in studying the spider community. 18 species were captured by all out search method. However, Malaise trap was found as a weak sampling method for spiders, only one individual of *Oxyopes sp. 2* got trapped in the Malasie trap.

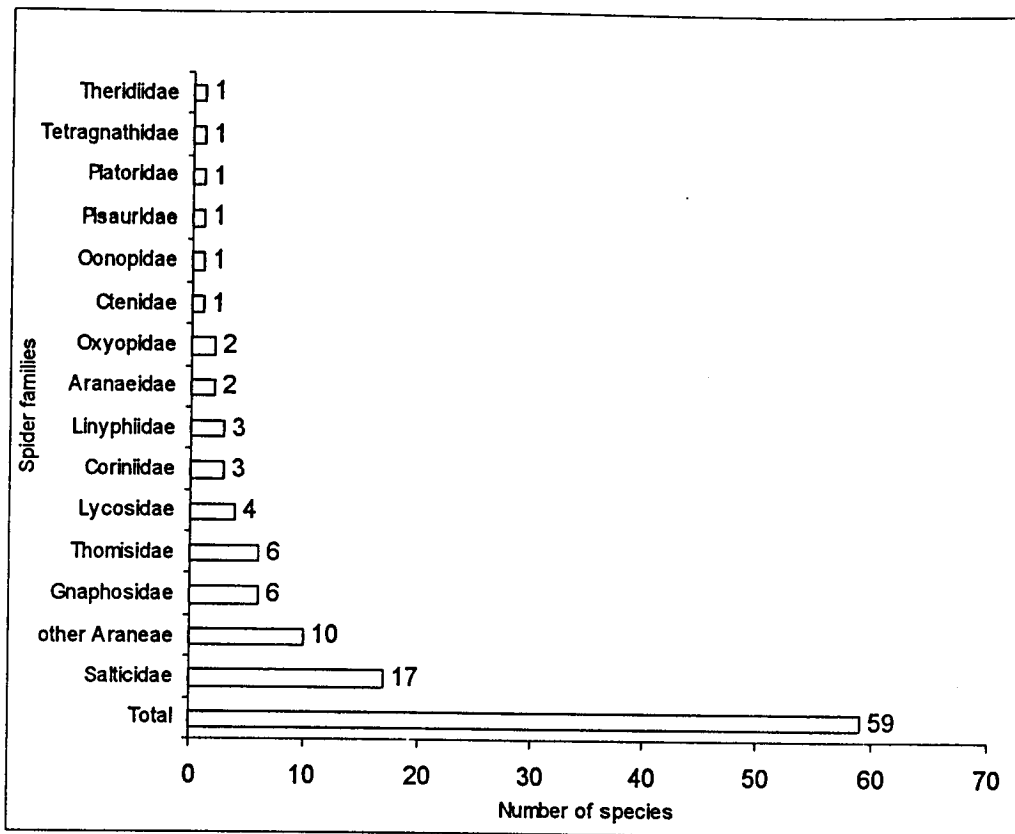


Figure 3.5 Bar diagram showing the total number of species in each of the spider families of the rice paddy agro – landscapes in Sringeri.

During crop season, the arthropod community of rice paddy agro – landscapes was sampled by Sweeping and Malaise traps. Only 73 individuals of spiders, from 15 species and 9 families were collected by using both the methods. But, 70 % of the entire data was contributed by a single species, *Tetragnatha sp*, of the family Tetragnathidae, and it was the third abundant family of the entire rice paddy agro – ecosystems of Sringeri. But, the population of this species was found building up only in the crop season, and their range hardly extended to other land use types. The family was not reported in the off-season fallows. See Table 3.4, Figure 3.5, 3.6 and 3.7, for the exploratory results of spider communities in Sringeri rice paddy agro – landscapes.

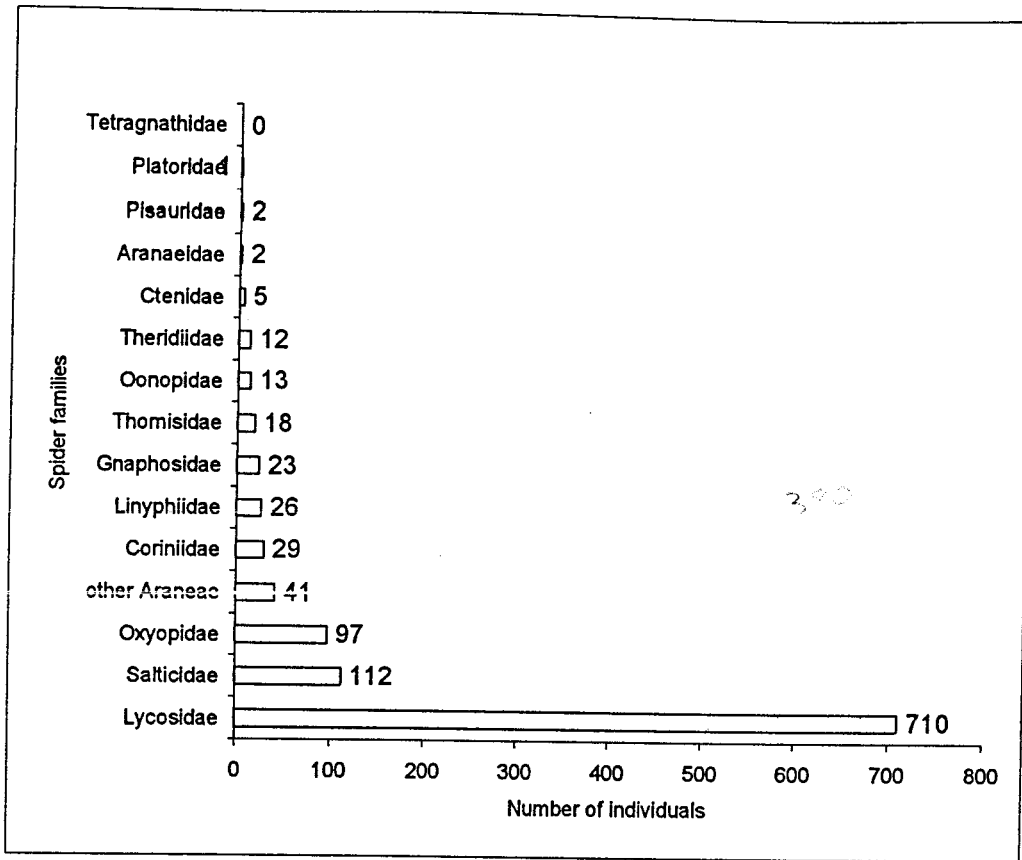


Figure 3.6 Bar diagram showing relative dominance of spider families of the rice paddy agro – landscapes in the fallow season

Though species like *Lycosa sp.1*, *Pardosa pseudoannulata* and *Pardosa sumatrana* (Lycosidae), *Oxyopes sp. 2* (Oxyopidae) and *Rhene flavigeara* (Salticidae) were found abundantly in the fallows during the off-season, these species were also active in the adjacent land use corridor habitats also, but, with a small population (See Appendix I).

Table 3.4 Summary of inventory of spiders in the Sringeri rice paddy agro-landscapes

	Fallow Paddy	Crop Paddy	Fallow + Corridor Off Season	Paddy + Corridor Crop	Whole study
Family	13	8	14	9	15
Species	39	10	56	15	59
Individuals	773	65	1091	73	1165

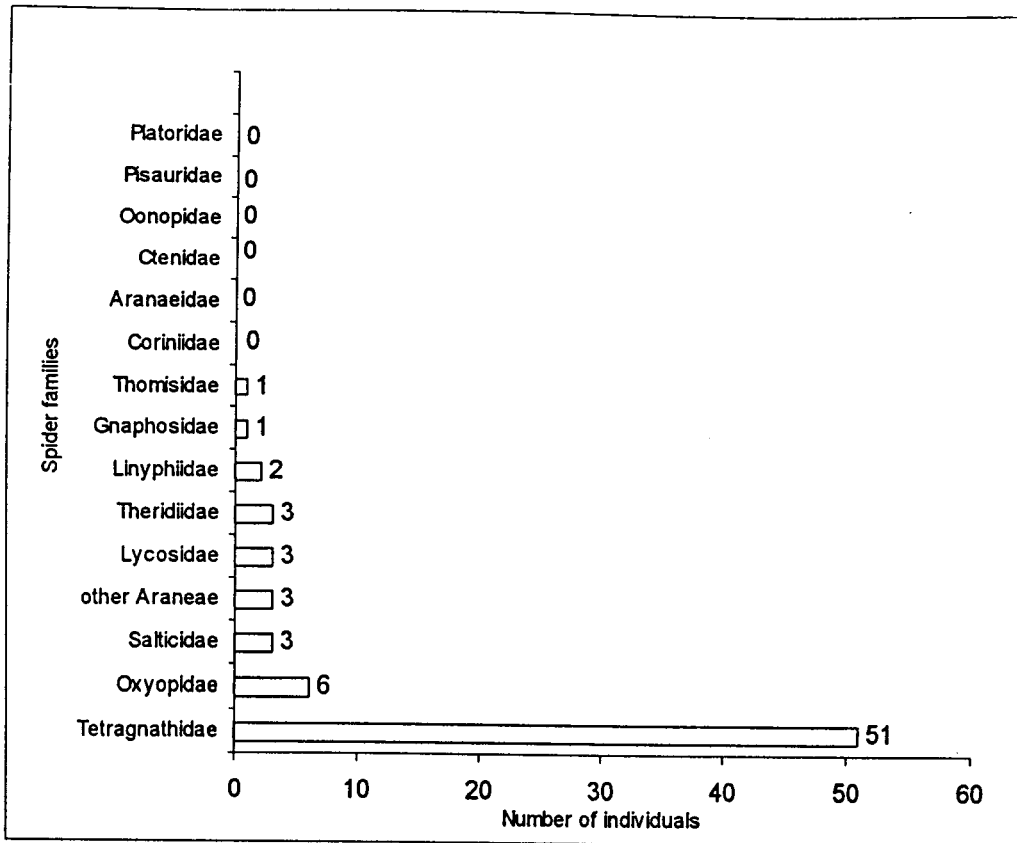


Figure 3.7 Bar diagram showing the relative dominance of spider families of rice paddy agro – landscapes in crop season.

ORDER COLEOPTERA

Families like Anthicidae, Carabidae, Chrysomelidae, Cleridae, Curculionidae, Elateridae, Laemophloeidae, Phalacridae, Scarabaeidae, Scolytidae, Staphylinidae, and Tenebrionidae were the common beetle representatives of paddy fields, and were seen abundantly mostly during off-season. However, some species of Curculionidae, Carabidae, and Cleridae were found abundantly in the crop season too. *Lebia sp.* (sp. 55a), *Brachinus sp.* (sp 37a), Harpalines (sp. 15a and sp 32a) were the abundant ground beetles of fallows. *Drypta sp.* and *Sceline sp.* (diurnal), several species of Scaritines, *Tachys spp.* and *Chlaenius spp.* (nocturnal) were the abundant predatory ground beetles in the paddy fields during crop season. Two species of tiger beetles (Cicindelidae), *Cicindela whitthilli* and *C. flavomaculata* were the other two abundant predatory species of crop season paddy fields. These two species were found exclusively in the crop season

paddy fields. However, several species of dung beetles (Scarabaeidae) were also located abundantly in the fallows.

ORDER DIPTERA

The fly population was exceptionally high in the rice paddy fields during crop season. However, as mentioned before, a good proportion of the Chironomids and Ceratopogonids represented the entire population density of the flies, and the occurrence of these species in the fallows was almost nil. The other abundant families of the rice paddy agro-landscapes were Muscidae, Dolichopodidae, Sciaridae, Ephydriidae, Phoridae, Tabanidae, and Asilidae. Most of these families were well represented in the crop season rice paddy fields relative to fallow season. However, some species of Cecidomyiidae, Dolichopoidae, Muscidae, Phoridae, Sciaridae, and Sphaerocerids were generalists, and were found almost in all the land use corridors through out the year along with rice paddy fields.

ORDER HETEROPTERA

The population of Order Heteroptera was high in the fallows; against a total of 804 individuals of the bugs, family Lygaeidae alone represented 52 % of the entire population. The family is considered as a generalist group, as they were spotted in the other land-use corridors too, especially in the Areca Orchards and Acacia plantations, along with fallows and cultivated paddy fields. The specialist predatory group, Reduviidae was poorly represented in the rice paddy ecosystems of Sringeri, and their activity was restricted mainly to the fallows.

ORDER HOMOPTERA

Of the 31 species of hoppers collected during the entire study, Cicadellids alone contributed 21 species. The population response of this large group was mixed; some specialist pest species, such as *Deltocephalus (Recilia) dorsalis*, *Nephotettix virescens* (Cicadellidae) and *Sogatella furcifera* (Delphacidae) were exclusive species of the cultivated paddy fields of Sringeri, and these species were not represented, both in fallows and other adjacent land use corridors during off-season. *Empoasca canara* sp. and *Deltocephalus* sp. were found to occur in the paddy fields during both the seasons; and some other species were abundant only in the fallows (see Appendix I).

ORDER HYMENOPTERA

The Order Hymenoptera was well represented by parasitic and predatory wasps. 21 of the total ^{of 16} 34 families comprised of typical parasitoid wasps. Scelionidae, Eulophidae and Ichneumonidae were the species rich families; however, the abundance of Ichneumonids was more or less restricted to the crop season. When species richness of parasitic families of crop and off-seasons were compared, except for Scelionidae, all other 16 parasitic wasp families were more specious ^{se} during crop season (See Figure 3.8).

The Table 3.5, given below illustrates the number of families, species and abundance of parasitic hymenopterans collected from various land use corridor habitats. The result on species richness and abundance across land use types between seasons is mixed. The results indicate that rice paddy fields during crop season, in comparison with off-season fallows, attract a large number of individuals from many species. The Figure 3.8 gives a clear picture of the dominant families of parasitic hymenopterans by species richness and abundance in rice paddy lands of both the seasons. See Table 3.5 and Figure 3.8 for more details.

Table 3.5 Count of Parasitic Hymenopteran families, species and individuals in various land use corridors and paddy fields in fallow and crop seasons

	Variables	SB	DS	AR	AC	Paddy
Offseason	Families	11	4	12	6	17
	Sobs	18	8	22	12	62
	Individuals	30	11	30	26	289
Crop Season	Families	11	6	16	4	19
	Sobs	24	9	31	7	71
	Individuals	29	16	62	10	886

what are
SB DS AR AC ?
what are labels?

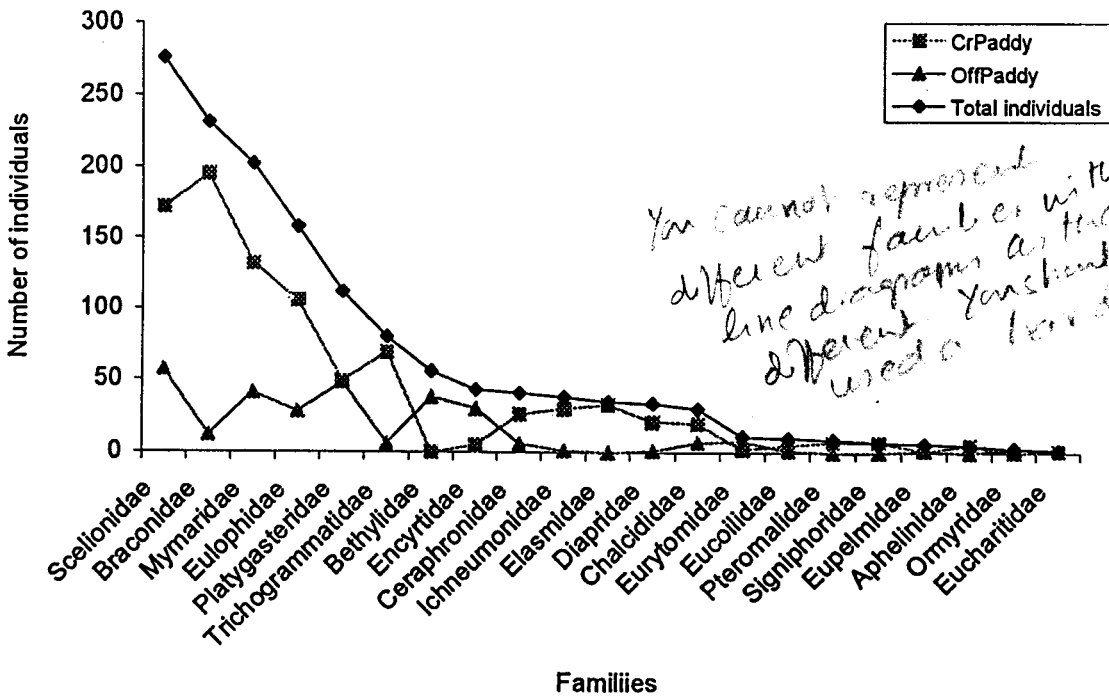
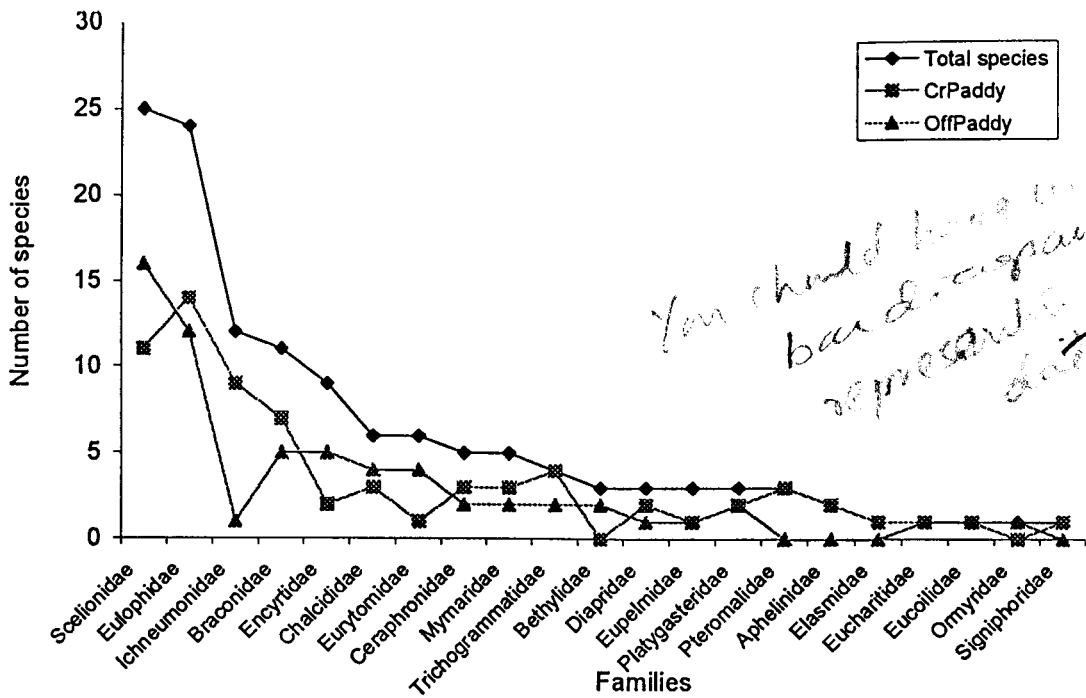


Figure 3.8 Line diagram showing number of species (upper panel) and individuals (lower panel) of parasitic hymenopteran families of crop (CrPaddy) and off-season paddy fields (OffPaddy). The total species richness and abundance of each family is also given.

Apart from parasitic wasps, Order Hymenoptera in the rice paddy lands also comprises of two other major guilds: predators and pollinators; 8 families of predatory wasps (Mutillidae, Sphecidae, Pompilidae, Scoliidae, Vespidae, Tiphiidae, Dryinidae, and Chrysididae) and 3 families of typical pollinators (Apidae, Halictidae, and Anthophoridae) were also observed in the paddy fields. Mutillid wasps were the abundant predatory insects of the fallow grounds. Nevertheless, the ant population of the fallows alone has contributed a good proportion of the entire hymenopteran data (5,723 individuals of 56 ant species identified in the fallows). However, only 58 individuals of 11 ant species were collected from the paddy fields during the crop season. The disparity is mainly due to the absence of pitfall traps in the crop season, which captures a considerable number of ground Formicids (4,854 individuals of 47 ant species were captured using pitfall traps from fallows). As the fields were water logged during cultivation period, operating pitfall traps was not possible.

ORDER LEPIDOPTERA

The lepidopteran population mainly consists of rice paddy pests available in Sringeri area. *Cnaphalocrocis medinalis*, *Spodoptera mauritia*, *Melanitis leda*, *Parnara mathias*, and *Nymphula fluctosalis* were the frequently captured moths and butterflies in the crop season paddy fields. Most of these insects were captured by sweeping, and a good proportion of the capture comprised of larvae of these pests too.

ORDER ORTHOPTERA

20 species of Orthopterans from 5 families were collected in this study. However, almost all the captures were from the fallows as well as from the adjacent land use types. Gryllids and Acridids were the abundant groups in the off-season, and are assumed to be more or less generalists, as they were spotted inside other land use types too. A major proportion of this capture was from the pitfall traps, particularly for the gryllids.

ORDER THYSANOPTERA

One or two unidentified species of Phlaeothripidae were observed to be minor pests of paddy saplings in the mid crop season. These species are more of generalists as they were spotted through out the year in all other adjacent land use types as well as in the fallows too, although they were less in number.

If you have the species then
also you can identify the
pests

3.3.2 VEGETATION COMMUNITY STRUCTURE OF SRINGERI RICE PADDY AGRO-LANDSCAPES

Vegetation studies of Sringeri rice paddy agro – landscapes comprised of the floral diversity estimation of the fallows (in the uncultivated season), paddy bunds (towards the end of crop season), and lower strata floral diversity of adjacent corridor habitats. See the methodology part of this Chapter for the detailed sampling methods.

A total of 33,439 plants from 210 species and 66 families were collected. Out of this, a total of 11,155 plants of 72 species from 26 plant families were identified only from the fallows during uncultivated season. 62 % of the families were monospecific, and Family Poaceae was the most species rich, followed by Family Scrophularaceae (See Figure 3.11). Results of abundance indicated that, 70 % of the fallow inhabitants were represented by > 10 individuals. Family Poaceae (41 %) was the most abundant, comprising 11 species (Figure 3.11). Family Asteraceae, though ranked fourth with 6 species, contributed only 21 % of the entire data. Whereas, Family Scrophularaceae although represented by 10 species, comprised only 3 % of the entire stand density. See Figure 3.12 for the percent abundance of top 10 families of fallows of Sringeri rice paddy agro – landscapes. During crop season 17,240 individuals from 125 species and 32 families were obtained from the paddy bunds. 60 % of the families were monospecific, and other 40 % of the families comprised of more than 2 species (see Figure 3.9). Percent abundance of top 10 families of paddy bunds is illustrated in Figure 3.10.

In the corridors, family (51 families), and species richness (135 species) were considerably more than any other land use types. But, the results have shown that nearly 67 % of the data was dominated by monospecific families, and 53 % of the families were represented by less than 10 individuals. This shows that compared to fallows or paddy bunds, floral diversity in the corridor was significantly more, in terms of rare species. Family Poaceae was the most species rich (23 species), and abundant (35 %). As in paddy bunds and fallows, Family Cyperaceae, Asteraceae, and Scrophularaceae were the next specious families of corridor habitats. However, family Fabaceae was one of the most abundant families in the corridors. See Appendix II for more details for species assemblages of rice paddy bunds, fallows and four land use corridor habitat types. The relative abundance of top 10 families of corridors has given in the Figure 3.13.

In both the seasons, though sampling was conducted from all the three different levels (fallows, bunds, and corridors of four types), family Poaceae was the most species rich. A number of wild relatives of rice paddy plants are included in family Poaceae. The other four dominant plant families at these two strata were Scrophulariaceae, Cyperaceae, Asteraceae, and Rubiaceae. On abundance data, family Poaceae (50 %) dominated over rest of the families at all three levels; followed by Family Asteraceae, and Cyperaceae.

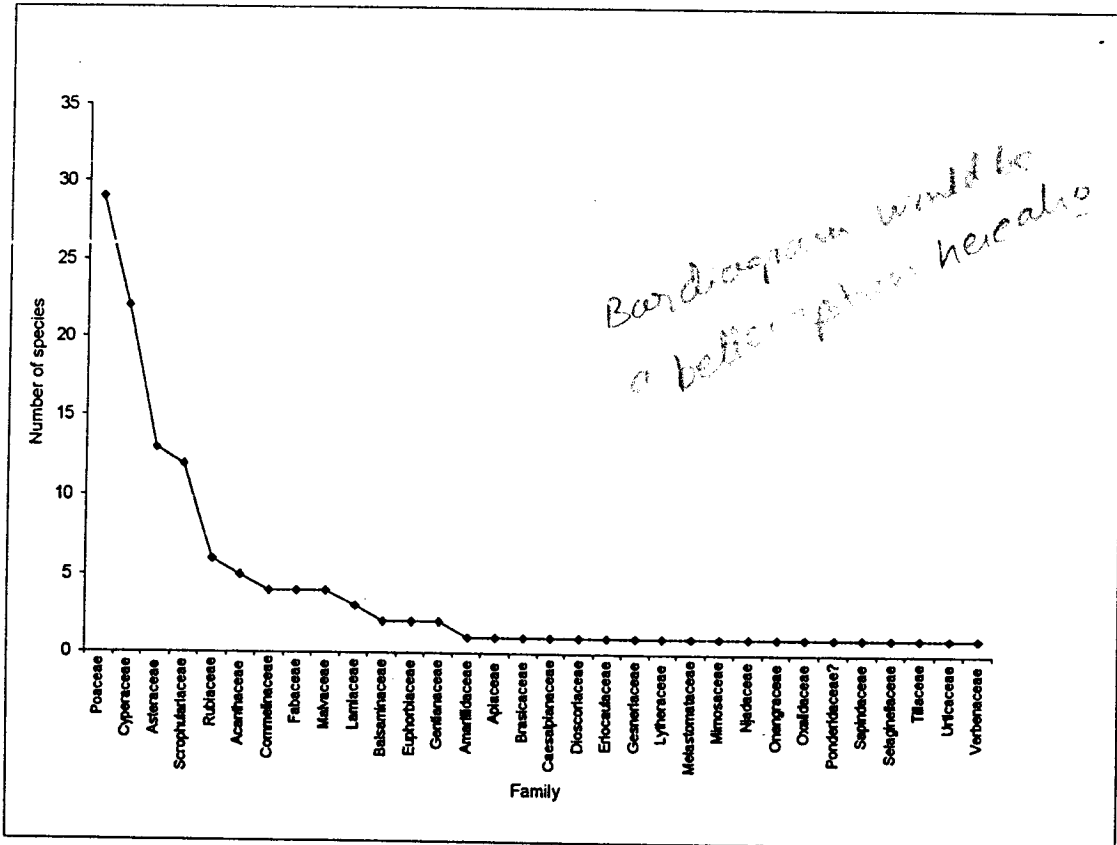


Figure 3.9 Line diagram showing number of species of each family of plants of rice paddy bunds.

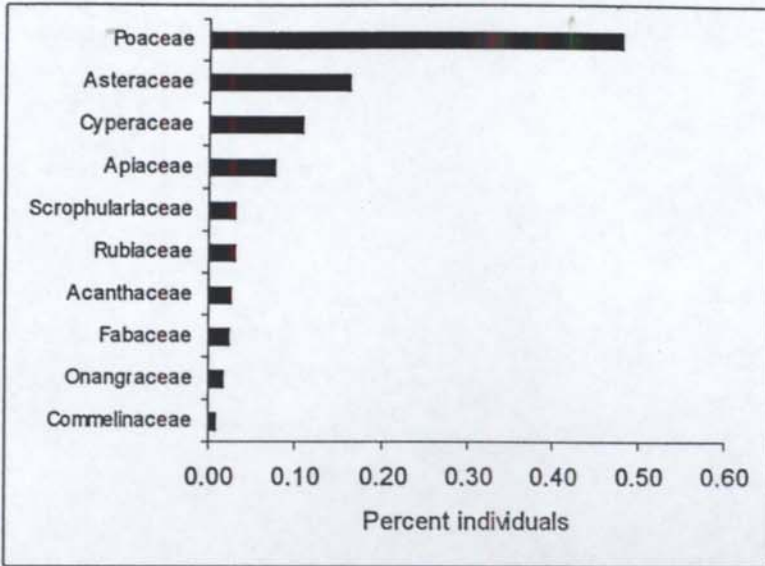


Figure 3.10 Bar diagram showing percent abundance of top 10 families of plants of rice paddy bunds

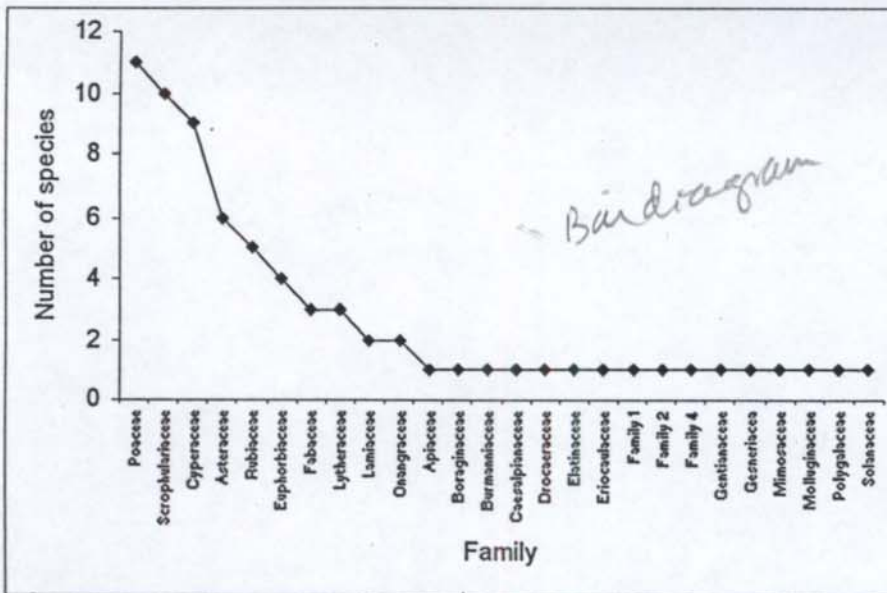


Figure 3.11 Line diagram showing the species richness of 26 families of flowering plants in the fallow paddy fields

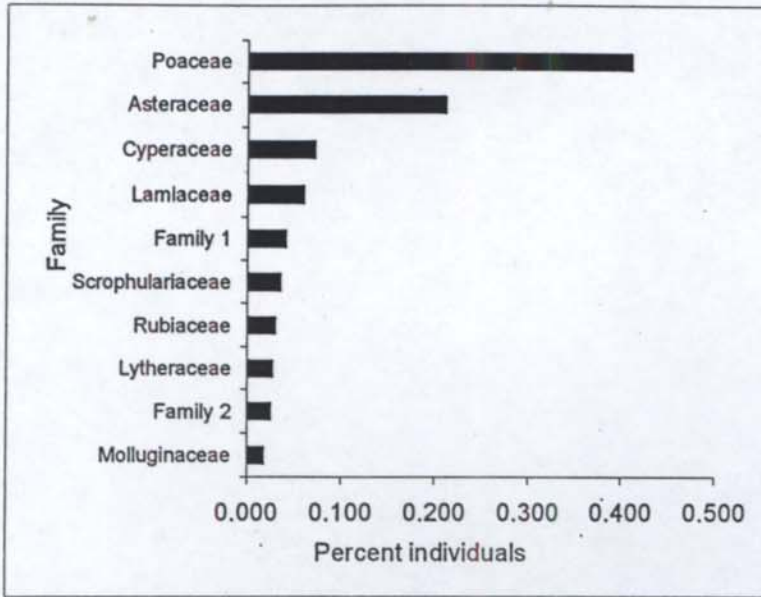


Figure 3.12 Bar diagram showing percent abundance of top 10 families of flowering plants of fallow paddy fields

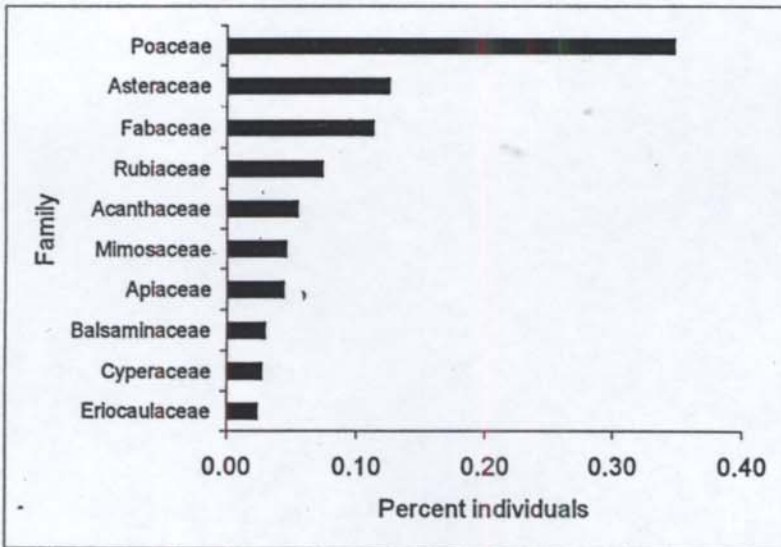


Fig 3.13 Bar diagram showing percent abundance of top 10 families of lower strata vegetation of the corridor habitats of Sringeri rice paddy agro - landscapes

Several species of fruiting weeds were observed inside paddy fields; a total of 21 families and 92 species were enumerated for the crop season paddy bunds, which was 46 species from 20 families in the fallows. Poaceans (27%) and Cyperaceae (27%) were the

dominant fruit bearers of the paddy bunds, while it was Asteraceae (20%) and Poaceae (17%) in the fallows. While studying the flowering weeds of paddy fields, Poaceae (26%) and Cyperaceae (16%) were the dominant families of the crop season paddy bunds; while it was family Asteraceae (24%) and Poaceae (22%) in the rice paddy fallows. These fruiting and flowering plants of the rice paddy agro – ecosystems do have a key role in maintaining arthropod biodiversity of rice paddy fields.

3.3.3 MAJOR PESTS AND THEIR NATURAL ENEMIES OF SRINGERI RICE PADDY AGRO - ECOSYSTEMS

A wide range of arthropods was found feeding or damaging various stages of rice paddy plants of Sringeri rice paddy agro – ecosystems. However, only six species of insects were found extensively feeding on rice paddy saplings. *Nymphula depunctalis*, *Cnaphalocrocis medinalis*, *Pelopidas mathias*, *Melanitis leda ismene*, *Euproctis sp.*, and *Leptocorisa acuta* were the 'locally major pests' of Sringeri rice paddy agro-ecosystems. Except for *Leptocorisa acuta*, none of these pests have attained the status of the major rice paddy pests in India. A brief description of each of these pests, their nature of damage, and natural enemies (if encountered) is given below. See Plates 3 and 4 for photographs of major pests of Sringeri rice ecosystems.

NYMPHULA DEPUNCTALIS (GUENEE)

Nymphula depunctalis is a lepidopteran pest (Family: ~~Pieridae~~ ^{Pyralidae}). It is commonly called as rice case worm or rice case bearer. In Sringeri the pest is known by its vernacular name, *bili chitte* (= white moth). It is a common defoliator of Sringeri rice paddy agro – ecosystems. The caterpillar cuts leaf tips of paddy saplings to make the cases; however both the ends of the cases are open. The caterpillars are semi-aquatic (Viraktamath *et al.* 1974), and having tubular tracheal gills for aquatic respiration. The larva reaches a maximum length of 15mm, and pupate in the final larval case, by closing both ends of the cases, and attach themselves to the culms of the rice paddy saplings or other wild grasses by one of its lateral margins. The pupation continues for an average of 6.5 days, which ranges from 5 – 11 days. Viraktamath *et al.* (1974) has studied the detailed biology of *Nymphula depunctalis*. The damage due to *N. depunctalis* occurs mainly by defoliation, by scraping the green tissues of leaves, which leave behind the white epidermis. Usually

infested plant saplings have been reported regaining their growth if pest outbreak is not heavy or other defoliators are not active at the same time. In some cases, the growth will be stunted, which results in loss of vigour of saplings, and cause a delay in attaining maturity.

In Sringeri, the damage due to *N. depunctalis* was severe in the Kharif season, which had compelled most of the farmers to apply pesticides like Metacid or Democron to eradicate the pest. However, the defoliation of paddy saplings in Sringeri rice ecosystems appeared to be a joint effort of *Nymphula depunctalis* and *N. fluctosalis*, which is a close relative of the former. However, 80 % of the defoliation could be attributed to *N. depunctalis*. The damage was initiated from the late nursery stage, and the severe infestation started 20 Day After Transplantation (DAT), and the infestation continued until the saplings reached an age of nearly 60 days. Infestation by the case worm was more in the paddy saplings of the permanently water-logged fields. Severe damage due to this pest was observed in 4 of the 21 study sites.

In Sringeri rice ecosystems, *N. depunctalis* pupated both above and below the water surface. However, nearly 75 % of the pupae were seen below the water surface. It was not clear, whether the larvae themselves move beneath the water surface and pupate, or having pupated above water, the continuous rain submerged them. In both cases, the moths emerged successfully, both in the field, and also in the laboratory. Pupal period ranged between 4 – 12 days, with an average of 7 days.

Two major natural enemies, with potential in controlling the larval stages of this pest is reported; one is a water spider, *Pisuara sp.* (Family: Pissauridae), which predate on the floating larvae, and another is a parasitic wasp, *Litochila sp.* (Hymenoptera: Ichneumonidae), which is a specific parasitoid of the case worm pupae. However, one species of damselfly (Odonata: Coenagrionidae) was recorded as a major predator of the adult moths in this study.

The role of the Ichneumonid wasp, *Litochila sp.* in controlling the pest was studied both in the field and laboratory in Sringeri. The wasp attacks the early pupal stage of the rice case worm. The host searching behavior of the wasp was very peculiar. The wasp landed in the middle of the rice paddy culms in most cases, and straight away walked towards the water surface in search of the case worm pupae. While moving down,

the wasp actively engaged in tapping the leaf surfaces with its antennae. On reaching the water surface, the wasp usually slowed down for a while, and vigorously beat the water surface with its antennae in order to get a stimulus from the case worm pupa. If the pupa was not sensed below the water level, the wasp usually spent an average of 5 seconds there, and then moved to the very adjacent paddy sapling. However, once the wasp senses the host pupa, it decreased the beating frequency on the water surface, and slowly crawled beneath the water surface, till it reached the adhered pupa. The wasps could spend a maximum of 1.3 minutes, under water, with an average of 55 sec. The wasps also moved a maximum distance of 2.5 cm below water surface. Nearly 70 % of successful parasitism on the rice case worm pupae due to these wasps was recorded in the laboratory experiments.

Cnaphalocrocis medinalis (Guenee)

C. medinalis is a pyralid moth pest causing serious damage to the mature saplings of the heavily fertilized rice paddy fields. The pest is commonly called as rice leaf folder, and according to Sringeri farmers, this is another *bili chitte* (= white moth). The larvae of this pest are considered as a serious defoliator of rice paddy saplings in some parts of the country, and also in Southeast Asian countries. The caterpillar is slightly 'rubbery', and very active, and always seen inside the leaf folds. They feed completely upon the green tissues of the leaves, before migrating to other sapling. Although they are recorded throughout the year on wild grasses and herbs, the pest attack on rice paddy saplings is severe during rainy season.

In Sringeri rice ecosystems, the *C. medinalis* infestation starts immediately after the application of Supala fertilizer complex, may be ^{at} in the 40 – 50 DAT paddy fields. The pest attack was found till the end of vegetative growth, and in some study sites, infestation extended until the middle reproductive growth stages of rice paddy sapling. However, except three farmers, no other farmers have claimed it as a serious pest to their paddy field, and no pesticide application against it was reported. Observations during this study indicated that most of the paddy agro – ecosystems of Sringeri area were heavily infested by this pest, and the infestation was severe towards the end of October in both the study years.

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A new ichneumonid species, *Scenocharops sinui* sp. nov. (Sudheer and Narendran, 2005) is identified and reported as a potential insect natural enemy of this pest in Sringeri. It is a pupal parasitoid of this pest, and wide spread in the rice paddy agro-ecosystems of Sringeri. Apart from this, another pupal parasitoid, *Brachymeria* sp (Hymenoptera: Chalcididae), and a couple of larval parasitoids were also recorded. The two major larval parasitoids were *Apanteles* sp. (Hymenoptera: Braconidae), and *Elasmus* sp. (Hymenoptera: Elasmidae). *Trichogramma* sp. (Hymenoptera: Trichogrammatidae) was identified as an egg parasitoid of this pest in Sringeri.

Pelopidas mathias (Fabricius)

It is a hesperid (Lepidoptera: Hesperidae) butterfly, and is commonly called as rice ~~swarm~~. However, no vernacular names are available for this pest in Sringeri. The larvae feed on the entire leaf tissue, and leave behind the midrib portion of the leaves. The larvae construct a chamber, either by rolling the tip of the leaves, or ^{with silk} spinning two margins of the same leaf, or tying two adjacent leaves of the same plant or ^{feeding attachment} two different plants. The larvae are active ~~in the~~ night, and usually rest in these leaf chambers in the daytime. Although it is a common pest in all kinds of rice agro – ecosystems, they are very active in the upland rice paddy fields, where a number of diverse microclimate habitats favor the multiplication of these pests.

In Sringeri rice paddy agro – ecosystems, the detrimental impact of this pest was moderate or below average. The infestation due to this pest started during the early vegetative phase of the transplanted paddy fields; however the infestation was severe in the 30 DAT paddy fields. Moderate infestation of the pest was seen in paddy fields with closely planted saplings (whose leaves overlap), and in fields, where there is increased growth of saplings due to the heavy input of fertilizers. In the heavily infested paddy fields, an average of 6 larvae was counted in a 5 sq m area. The larvae attained a maximum length of nearly 5 cm in Sringeri rice paddy fields, and pupae, which were dark brown, and like a question mark with pointed ends, are usually seen inside the leaf chambers.

Five potential natural enemies of *P. mathias* were recorded in Sringeri rice paddy agro – ecosystems during this study. Three species of braconid wasps, *Apanteles* sp 1, *Apanteles* sp. 2 and *Cotesia* sp. were the common larval parasitoid of this pest. All the

three species were gregarious larval parasitoids. *Brachymeria ascarinata*, and *B. lasus* (Hymenoptera: Chalcididae) were identified as the potential pupal parasitoid of this particular pest. For both the cases, a single parasitised pupa produced an average of 6 progeny. Two hyperparasitoids, one unidentified ceraphronid wasp (Hymenoptera: Ceraphronidae), and *Pteromalus sp* (Hymenoptera: Pteromalidae), of *Apanteles sp. 1* were also identified in this study.

Melanitis leda ismene Cramer

It is a nymphalid (Lepidoptera: Nymphalidae) butterfly, and adults are commonly known as common evening brown. The damage is caused by the caterpillars, commonly known as green horned caterpillar. This pest has no local Kannada name in Sringeri. The adults are large butterflies, and active only in the evening, after dusk. However, as the name indicates, the larvae are having two pairs of horns, one on its square shaped head, and another pair at the rear portion. The damage caused by this pest can be easily confused with that of *P. mathias*. The larvae usually eat up the whole leaf matter, and leave behind the leaf midrib portion. However, unlike rice ^{skipper} ~~swift~~ larvae, *M. leda* larva doesn't make any leaf case. The larva usually rest on the lower or upper surfaces of the paddy leaves, and are active in the daytime also.

In Sringeri rice paddy agro – ecosystems, this pest was very active. The adult butterflies usually lay eggs in a clutch of 3 – 6 on the ~~underneath~~ ^{underside} surface of ~~the~~ paddy leaves. The final instar larva was 6 cm long, and weighed a maximum of 0.65 gm. The pupae were robust, smooth green with a constriction near the head part, and attached on the lower surface of the leaves by a small stalk. The fresh pupa weighed a maximum of 0.60 gm. Before emergence, the colour of pupae changed to dark brown. In the entire study, neither larval nor pupal parasitoids of this particular pest was recorded; however caracasses of the larvae were found in the paddy fields, and it was assumed that, they were killed by some microbial agents.

Leptocorisa acuta Thunberg. *Alydidae*

It is a coreid (Heteroptera: ~~Coreidae~~ ^{Alydidae}) bug, and is one of the major pests in all the rice growing areas around the world, and is commonly known as rice bug. The farmers of Sringeri call it as *Bambula* in Kannada. Both the nymphs as well as the adult bugs caused

NO!
only in
old world
Tropics

damage. The bugs usually affect the early reproductive stages of rice paddy saplings, by sucking the milky juice of the fresh grains. The damage due to this pest is considered as high, compared to any of the other pests, which attack the rice paddy saplings in the vegetative phase. The infestation resulted in deformed or chaffy grains, and if the infestation is very high, it affects the gross production of rice.

In Sringeri rice paddy agro – landscapes, although the pest occurrence was high, the damage due to it was relatively less when compared to irrigated paddy fields of the plains. The first incidence of this pest during my study, in Sringeri rice paddy agro – ecosystems was noted in mid October, which was 45 days after transplantation. The first egg clutch of this pest was collected from a shrubby plant in the Areca orchard, well before it was collected from rice paddy fields. However, before the bugs migrated to the rice paddy fields, a good number of these bugs were observed on other Poacean relatives, which were seen in the paddy bunds. The eggs were brown, oval, and usually ~~were~~ arranged in a clutch of ^{one} ~~single~~ or two ^{rows} ~~lines~~ on the upper as well as lower surface of the paddy leaves. In some of the study sites, nearly 70 individuals of the adult and nymphs of this bug were counted in a sq m. area inside paddy fields. However, in others the pest incidence was almost absent. From the analysis, it was understood that the infestation was more in the paddy fields, where the cultivation practices were delayed. When compared to Kharif season, the crop loss due to this bug was quite high in the summer cultivated rice paddy fields. Although no potential natural enemies of this pest were observed in this study, a Scelionid wasp (Hymenoptera: Scelionidae) was found to ~~parasitise the eggs of~~ *L. acuta*, both in the Kharif and Rabi cultivation seasons. The potential of this wasp as an egg parasitoid is under investigation.

How do they parasitise the egg?

Euproctis sp.

It is a common hairy caterpillar (Lepidoptera: Lymantriidae), which occasionally becomes a serious pest of paddy. The adult moths are small, and pure white with plumose antenna. The earlier larval stages are reddish brown, and hairy. However, as it matures, the larvae gain size, and become dark brown or black in colour. The pupation usually takes place in the soil.

This species was not a serious pest of paddy in the Kharif season. During this period, the pest was feeding on the leaf tissues. When compared to other pests, its

abundance was very low during this period. However, in the Rabi season, the damage due to this pest was locally very high. The larvae were found to feed on the anthers of the rice flowers rather than on the green tissues of leaves during this period. The larvae were also found feeding on the flowers of other wild Cyperacean plants. Moreover, the occurrence of this larva was also relatively more compared to Kharif season. But, most of the farmers in Sringeri were not aware of this particular damage. In this study, no particular natural enemies were encountered for this pest in Sringeri.

The other common lepidopteran pests, though not major, were *Orsotriaena medus* (nigger butterfly), *Spodoptera spp.* (Swarming caterpillar), *Taractrocera/Ceramus* (Tamil grass dart), *Taractrocera maeivius* (Common grass dart), and *Lambrix salsala* (Chestnut bob) in Sringeri rice paddy agro - ecosystems. Although the impact was not severe, three other major pests were leafhoppers (*N. virescens*, *Deltocephalus (Recelia) dorsalis*, and *S. furcifera*). However, the pest attack by *Nilaparvata lugens* and *Scirpophaga incertulus* was almost nil, at least for the study period in Sringeri. However, a number of farmers had complained of hopper burn (*b/nki roga* in Kannada), and *S. incertulus* (*Gandula* in Kannada) incidence in Sringeri, about four years prior to this study.

3.3.4 QUANTITATIVE ESTIMATION OF SOIL INGREDIENTS OF SRINGERI RICE PADDY AGRO - LANDSCAPE

3.3.4.1 Soil ingredients of rice paddy agro – ecosystems of Sringeri

Soil parameters like pH, Organic Carbon, Average Phosphorus (Av. P_2O_5 Kg / Acre), were estimated for each of the study sites and were used for further analysis, like correlation and regression studies, which is given in Chapter 4. The following part explains the variation in the data for these three soil components of rice paddy agro – ecosystems of Sringeri.

Soil pH

The soil of rice paddy fields of Sringeri area was acidic, and ranged between 4.3 and 5.3. The box plot (Figure 3.14) for the soil pH of each of the rice paddy fields studied showed that soil pH differed between sites, and this could be attributed to the soil type, rock erosion, rainfall, and also the farming practices (fertilizer, and pesticide application). The average soil pH was 4.8 for Sringeri rice paddy fields. However, One way ANOVA

results have shown that the difference in the mean soil pH of rice paddy fields was not significantly different between study sites ($F_{20} = 1.33, P = 0.25$).

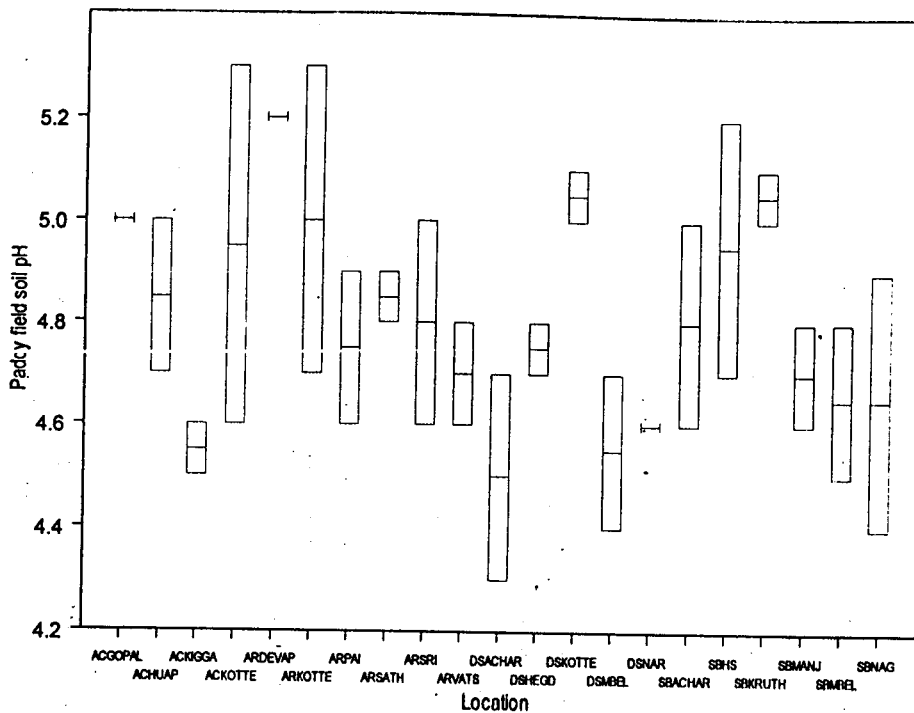


Figure 3.14 Box plot showing median and variation in soil pH of rice paddy agro – ecosystems of 21 study sites

Percent Organic Carbon content (% OC)

This is an important soil parameter, and is highly related to the biomass and organic compost input to the soil. However, as with pH, Organic Carbon content of the soil was also highly related to rainfall, soil leaching, and other farming practices etc.

The box plot (Figure 3.15) showed a huge variation in the percent Organic Carbon content of the rice paddy field soil between study sites. It varied from 0.54 % - 1.99 %, with an average of 1.14 % per acre. One-Way ANOVA showed that the % OC between study sites was significantly different ($F_{20} = 2.73, P = 0.01$).

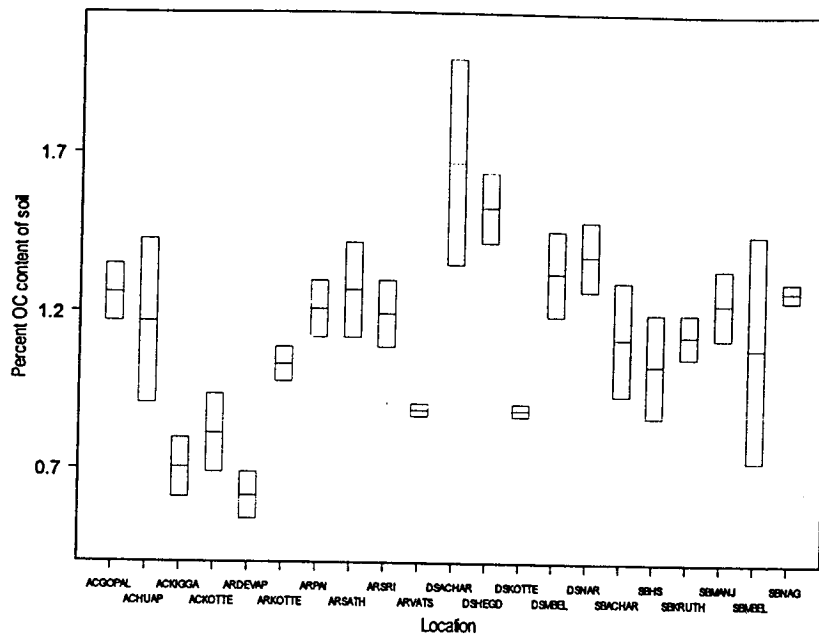


Figure 3.15. Box plot showing median and variation in the percent Organic Carbon (per acre) content of the soil of rice paddy fields of Sringeri

Average P_2O_5 content of soil

Phosphate content of the soil is assumed as the direct attribute of the fertilizer input rather than the biomass input to the soil. It was assumed that, by estimating this particular component of the soil of rice paddy fields, a general idea of the inorganic fertilizer input to the paddy field by the farmer would be available. This was found true, after a discussion with the farmers of the corresponding paddy fields. The ^{Supnath} ~~supnath~~ (Phosphate complex) fertilizer input to the paddy fields was exceptionally high in study sites like ACHuappa and ARVatsa.

The box plot (Figure 3.16) showed that the average P_2O_5 content of the soil in the paddy field ranged from 2 kg – 8 kg, with an average of 3.54 kg / acre. One-way ANOVA results have shown that the difference in the average phosphate content of the soil was significant between study sites ($F_{20} = 2.91, P = 0.009$).

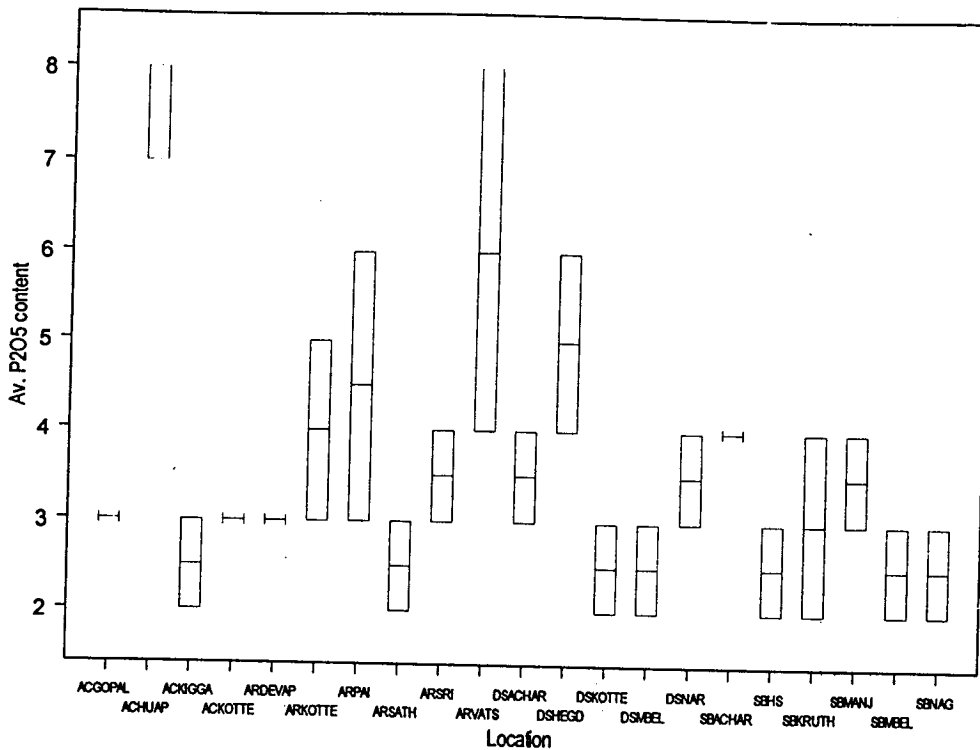


Figure 3.16 Box plot showing median and variation in the average P_2O_5 content (Kg/Acre) of the soil of rice paddy fields of Sringeri

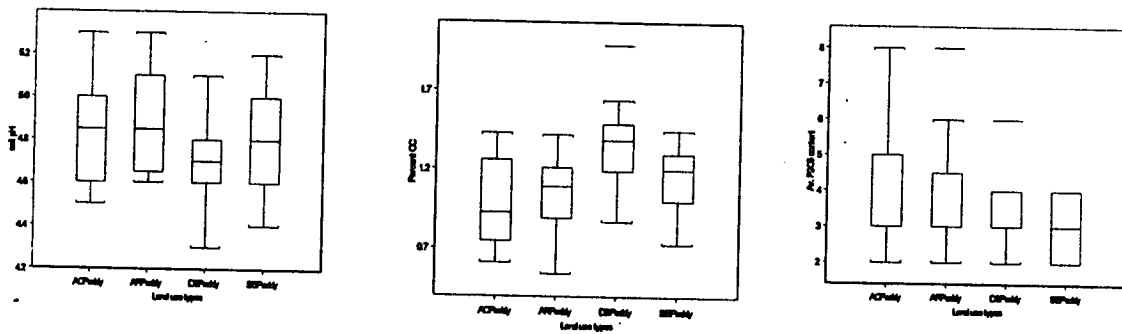


Figure 3.17 Box plot showing variation in the soil pH, percent Organic Carbon content (% OC), and Average P_2O_5 content of rice paddy fields adjacent to four land use corridor habitats

The box plot (Figure 3.17) for the paddy fields grouped for each of the four land use corridor types showed that maximum variation in the soil characters was in the Acacia adjacent paddy fields. However One-way ANOVA results showed that Mean soil pH and phosphate content of paddy fields, adjacent to four land use types were not significantly different ($F_{3,38} = 1.12, P = 0.35$; $F_{3,38} = 1.05, P = 0.38$ respectively). The Mean organic Carbon content of the soil was significantly different between paddy fields adjacent to four land use corridor types ($F_{3,38} = 3.55, P = 0.02$).

3.3.4.2 Soil ingredients of land use corridors adjacent to paddy fields

The soil characters of land use corridors adjacent to paddy fields were also studied.

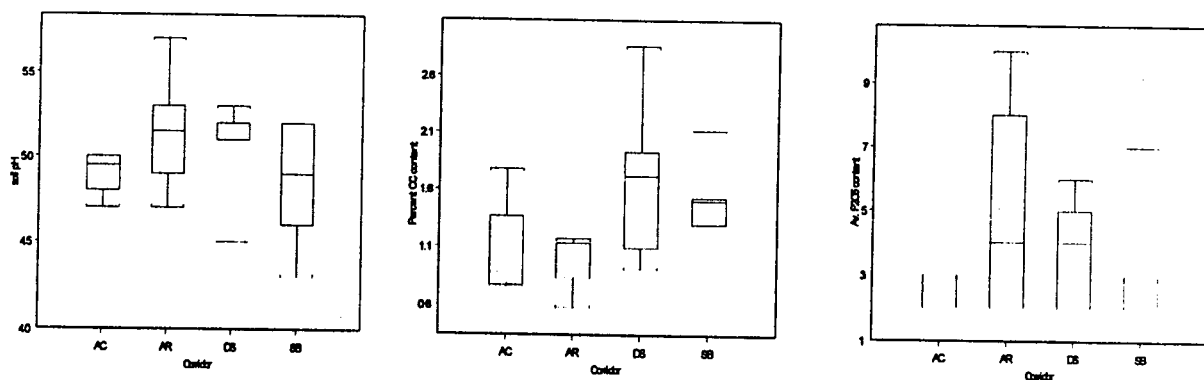


Figure 3.18 Box plot showing variation in the soil pH, percent Organic Carbon content, and phosphate in four land use corridors adjacent to paddy field (AC, Acacia; AR, Areca; DS, Degraded scrub; SB, Soppinabetta forest)

The box plots (Figure 3.18) indicate that soil pH of *Soppinabetta* forests varied greatly across study sites, when compared to other three land use types. Meanwhile, the pH of the soil in the corridors varied between 4.3 and 5.7, with an average of 4.9. However, the Organic Carbon content of the soil was more in the Degraded scrub forests relative to other land use types, and showed more variation between study sites. The percent of OC varied between 0.58 and 2.86, with an average of 1.29 %. The box plot shows that Areca orchard is rich in phosphate in comparison with the other three land use types, and the

variation between study sites was also more in AR. But, phosphate content of the corridors varied between 2 – 10 kg / Acre, with an average of 3.76 kg.

One-way ANOVA results were similar to those obtained for the paddy fields adjacent to four land use corridor types; the difference in both pH and phosphate content were not significantly different between corridor types ($F_{3,17} = 1.07, P = 0.38$; $F_{3,17} = 1.11, P = 0.37$ respectively). Where as, the difference in the soil OC content between corridors was slightly significant ($F_{3,17} = 2.90, P = 0.06$).

3.3.4.3 Soil temperature and humidity of rice paddy agro – ecosystems of Sringeri

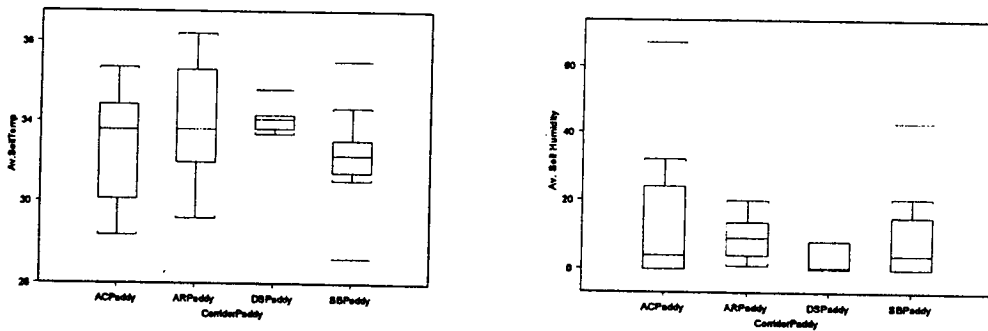


Figure 3.19 Box plot showing variation in soil temperature and humidity of paddy fields adjacent to four land use types in Sringeri rice paddy agro – ecosystems

The box plots (Figure 3.19) constructed on soil temperature showed that paddy fields adjacent to Degraded scrub forests were more or less homogeneous. Meanwhile, variance of soil temperature between study sites was more in the paddy fields adjacent to Acacia plantations. Soil humidity too showed same variance. Kruskal-Wallis rank ANOVA results have shown that the difference in both median soil temperature and soil humidity between paddy fields adjacent to four land use types were not significant ($KW H (df 3, N 32) = 3.23, P = 0.35$; $H (df 3, N 34) = 3.20, P = 0.36$ respectively).

3.3.5 SPECIES ACCUMULATION CURVE

3.3.5.1 *Arthropod data*

Species accumulation curve constructed on the total species richness of arthropods collected during study from Sringeri rice paddy agro - landscapes showed that neither total observed nor estimated species richness (Chao 2) reached asymptote. It indicates that the entire community of arthropods had not been fully sampled and that the true insect and spider richness of these agro-landscapes may extend well beyond the values predicted here. Although the total observed species richness was 814, the true richness of species was estimated to be as high as 1160.7 species (Figure 3.20).

Figure 3.21 illustrates species accumulation curve for total and predicted species richness of off (fallow) and crop season paddy fields, where the number of subplots of paddy fields (only PA 50 and PA 100 were considered, and 0 m of crop season was excluded) was plotted as the sampling effort. The data from pitfall traps, all out search method, sweeping and Malaise were pooled for each subplot for the uncultivated season, while the data from Sweep and Malaise were pooled for crop season.

For the uncultivated season, although a total of 451 species were collected using pitfall traps, all out search, sweeping and Malaise traps from the fallows, the true total species richness of the fallows was estimated to be 664.5 species using Chao 2,; the total estimated species richness of crop season (433.7) was found to level off against the total observed species, which was only 278 species, collected from Sweeping and Malaise samples. The results indicate that the sampling methods adapted were not at all sufficient to sample the entire arthropod community of both the fallows and crop paddy fields, as the total observed species accumulation curve for both off season fallows and that for crop season did not reach asymptote.

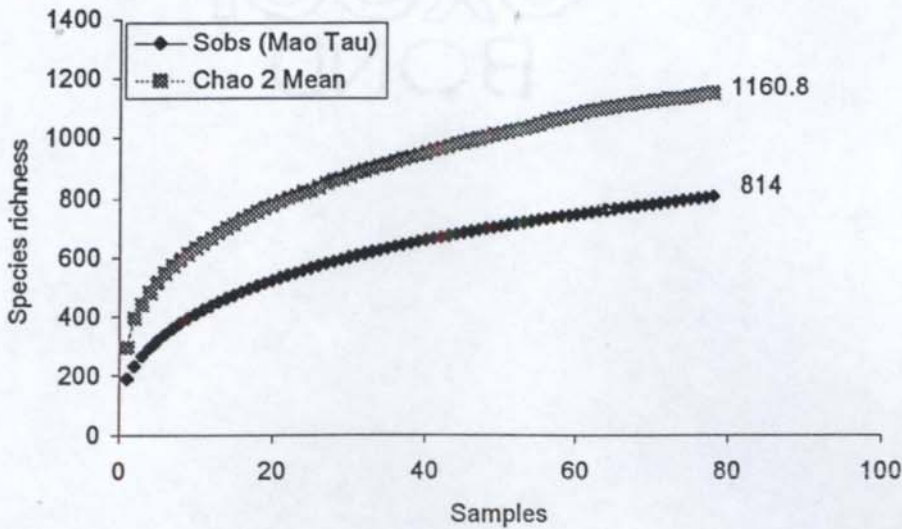


Fig. 3.20 Species accumulation curves for total richness of arthropods collected from Sringeri rice paddy agro - landscapes. Species richness across traps was pooled for each subplot of corridor, PA50 and PA100 across 21 study sites.

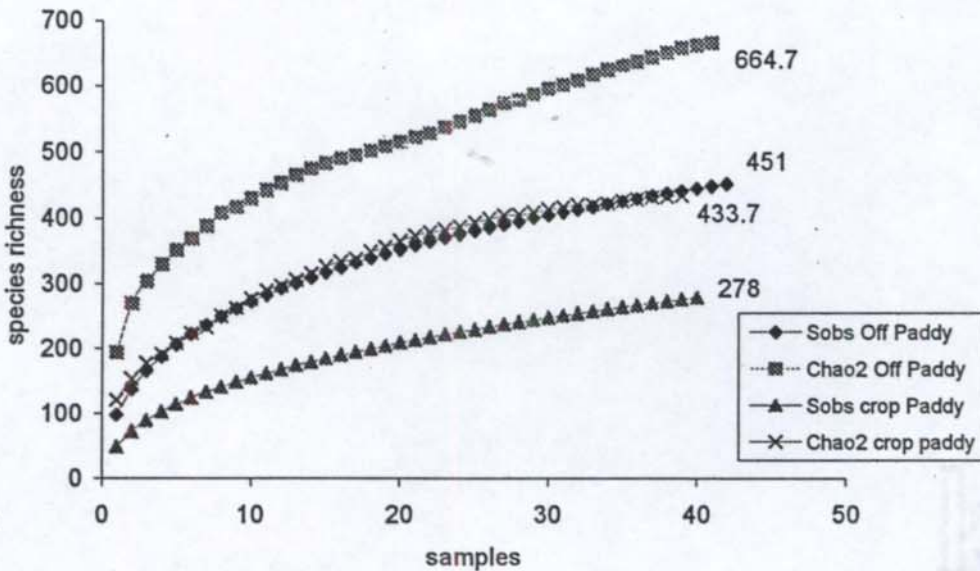


Fig. 3.21 Species accumulation curves for total observed (Sobs) and estimated richness (Chao 2) of arthropods of Sringeri rice paddy agro - ecosystems in off and crop seasons. Species richness across traps for each subplot (PA50 and PA100) of rice paddy fields of 21 study sites were pooled before analysis .

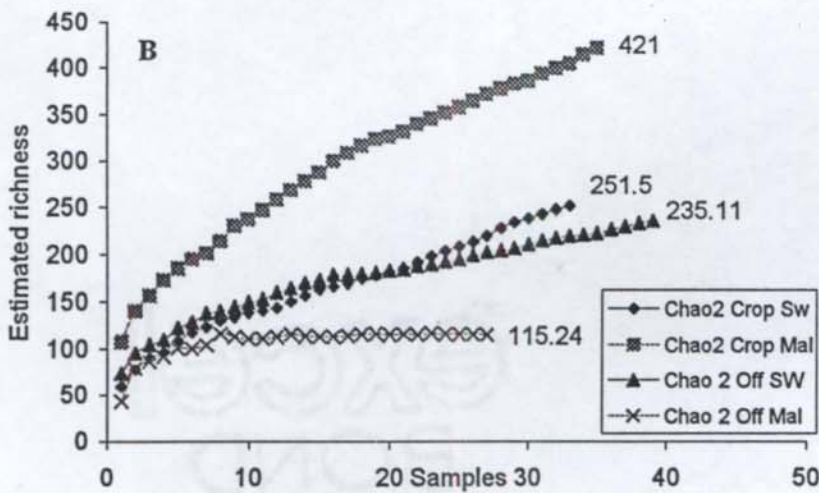
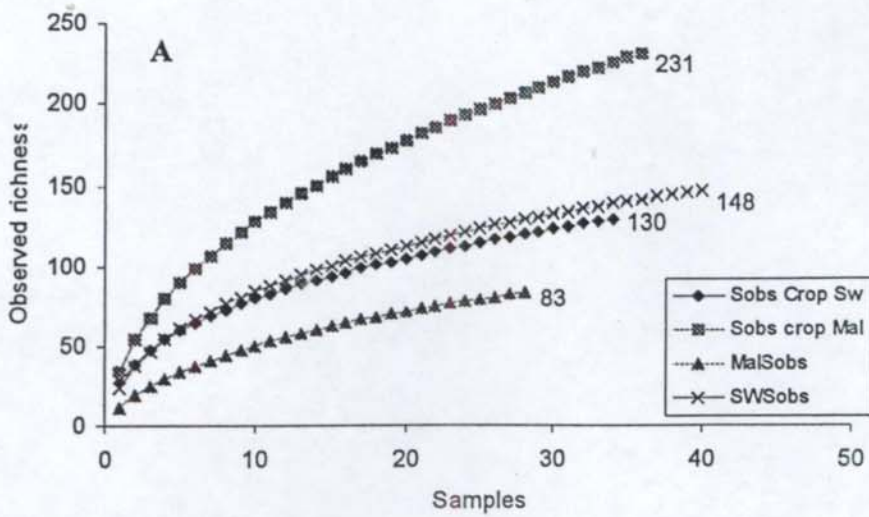


Fig. 3.22 Species accumulation curves for observed (A) and estimated (B) species richness of aerial arthropods of off – season fallows and crop season paddy fields. Species richness across traps of Sweep (SW) and Malaise (Mal) was pooled for each subplot, PA50 and PA100, of paddy fields of 21 study sites before analysis

Figure 3.22 presents observed and estimated species accumulation curves for aerial arthropods of fallows (offseason), and crop season paddy fields, which were collected with Sweep and Malaise traps. From figure 3.22A, it was apparent that the observed species richness of aerial arthropods of crop season paddy fields as collected on Malaise sample was relatively steep when compared to other species accumulation curves. This

indicates that the proportion of singletons to doubletons of Malaise samples of crop season paddy was high. However, a considerable difference in the total observed species richness between crop and off seasons was observed on Malaise samples, while the difference of observed species richness on sweep samples was marginal.

The accumulation curves constructed on Sweep and Malaise samples have shown that total observed species richness of aerial arthropods of fallows and crop season paddy fields were not fully sampled, and all curves were shooting up (Figure 3.22A). However, the predicted species richness almost leveled off, for all except Crop season Malaise traps, where the curve has shown that the traps laid were not sufficient to sample a good proportion of crop season paddy specialists (Figure 3.22B).

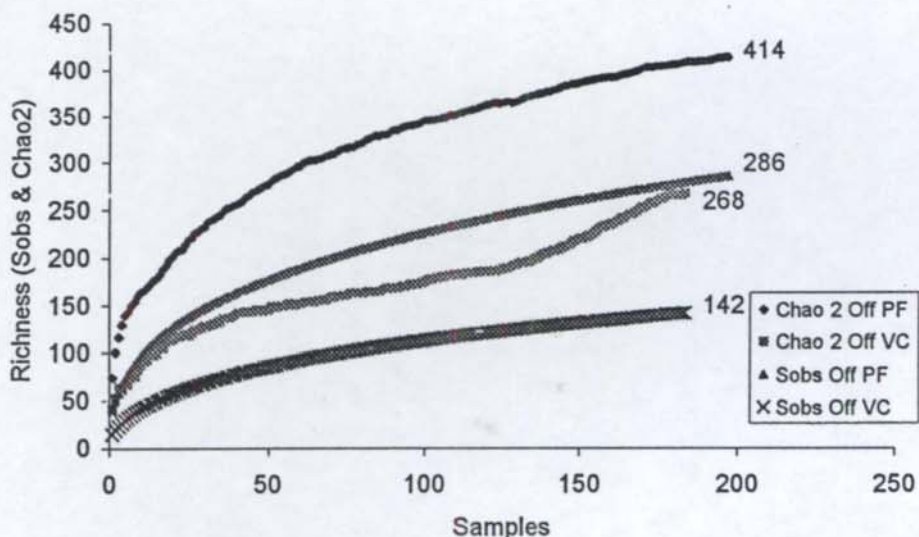


Fig. 3.23 Species accumulation curves for observed and estimated richness of arthropods on Pitfall traps (PF) and All out search (VC) from paddy fields of 21 study sites in off-season

In Figure 3.23, observed and estimated species collected on Pitfall (PF) and all out search methods (VC) were plotted against the accumulated traps. The species accumulation curves illustrated that a considerable proportion of fallow ground active arthropods was sampled in this study. All the four curves appeared to be leveling off.

3.3.5.2 Vegetation Data

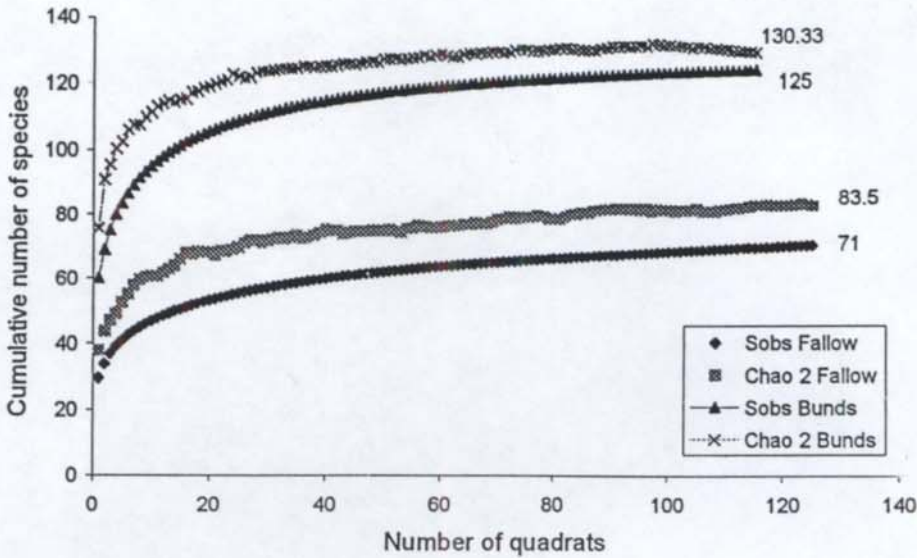


Figure 3.24 Species accumulation curves for observed (Sobs) and predicted (Chao 2) floral species richness of fallows and rice paddy bunds of Sringeri rice paddy agro - ecosystems

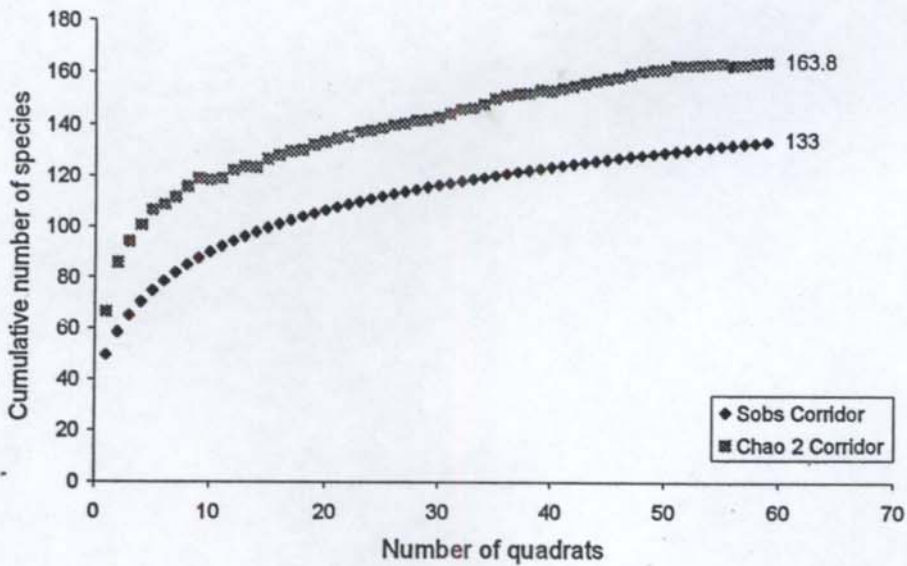


Figure 3.25 Species accumulation curves for observed (Sobs) and predicted (Chao2) species richness of lower strata flora of adjacent land use corridors of rice paddy agro - ecosystems

Species accumulation curves (Figure 3.24 & 3.25) constructed on floral species richness of fallows (offseason) and rice paddy bunds (crop season) have shown that a good proportion of rice paddy inhabitants of Sringeri agro – landscape were sampled, and the curves plateaued for both the measures. The difference between observed (Sobs) and expected (Chao 2) species richness was marginal. On the other hand, the species accumulation curve erected on lower strata vegetation of paddy adjacent land use corridors, which mainly comprises of weedy grasses, herbs, and younger saplings of tree species, has shown that quadrates used for the sampling were insufficient to capture a considerable proportion of the wild flora of these habitats. However, the number of quadrates used for the floral assessment of corridors was only half (58 quadrates) the number of quadrates used for fallow and bund floral assessment, where it was nearly 126 and 117 quadrates respectively.

3.4 DISCUSSION

3.4.1 ARTHROPOD COMMUNITY STRUCTURE OF SRINGERI RICE PADDY AGRO - LANDSCAPES

The terrestrial arthropod population is one of the major components of the rice paddy agro – ecosystems, which can be divided into rice pests, natural enemies and tourists. The study has brought out a total of 814 species of arthropods that include only the terrestrial insects and spiders.

34,242 individuals from 814 species of 179 families and 18 orders would be a considerable figure for any insect related agro biodiversity studies. Although most of the species richness accumulation curves for the observed species richness did not level off for any of the seasons, the near plateauing curves for most of the collection methods have shown that approximately 80 % of the ground dwelling arthropods of fallows, and > 65 % of the aerial active flying insects of paddy fields were captured in this study.

Order Coleoptera was represented by the most number of species, compared to other arthropodan Orders in the rice paddy agro – landscapes of Sringeri. Against a total of 26 families and 368 species list of Coleopterans of rice paddy agro – ecosystems of various parts of the world compiled by Rai *et al.* (2000), the present study has captured a total of 39 families and 252 morphospecies of terrestrial beetles, in the Sringeri rice

paddy agro – landscapes. However, the adjacent land use corridors alone have contributed nearly 35 % of this data, 80 corridor specific beetles were collected in this study. Another 75 % (172 species) were common both in the paddy fields as well as in the corridors. However, 84 species of these beetles (49%) were collected only from the fallow or crop season paddy fields, and another 51 % of beetles are shared between paddy fields and either one of the four corridor habitat types (See Appendix I for the habitat requirement of each coleopteran family and species). Except one species of Anthicidae, no beetle species were shared between the paddy fields of the two seasons. This could be due to the sampling artifact, as during crop season, ground dwelling arthropods were not sampled, by any of the methods.

Four major beetle families, Carabidae (45 species), Scarabaeidae (35 species), Chrysomelidae (32 species) and Staphylinidae (29 species), together contributed nearly 65 % of the entire beetle community of rice paddy agro – landscapes of Sringeri. However, except Chrysomelids, other three families were relatively more abundant in the paddy fields, particularly the fallow lands rather than corridors. The Family Cicindelidae is the most abundant family of the cultivated rice paddy fields of Sringeri, but the family was represented by only two species, *C. whitthilli*, and *C. flavomaculata*. Family Curculionidae, Elateridae, and Tenebrionidae were the other three species rich families of. Please see Appendix 1 for the ranks of each family based on the abundance. Although members of Carabidae are widely considered as one of the major predatory arthropod group, some of them are phytophages too, especially flower feeders. In this study, one species of *Harpalus* (Carabidae: Harpalinae) was found actively consuming flowers of a major Poacean weed on the paddy bunds.

Order Hymenoptera of Sringeri rice paddy agro – landscape was rich with a total of 246 species from 34 families. The present findings on Order Hymenoptera could be even comparable to the 254 species of wasps and ants provided by Barrion and Litsinger (1994) in their compendium on the taxonomy of arthropods of worldwide rice paddy agro – ecosystems. However, at the most 30 % of the entire Hymenoptera collected from the present study was represented by 76 species of ants. 42 species of these hymenopterans were exclusively found in the adjacent corridors of the rice paddy fields, and another 201 species were either found both inside the paddy fields and corridors or paddy specialists.

The study has brought out 117 species of parasitic wasps from the Sringeri rice paddy agro – landscape, is 47 % of the total hymenopteran species. Settle et al (1996) has catalogued 187 species of parasitoids, which include the insects outside hymenoptera too, from the lowland rice paddy lands of Philippines. According to Heong et al (1991), Mymarids, Braconids, Diapriids, Pteromalids, and Trichogrammatids were the dominant parasitoids of Philippines rice paddy fields, which contradicts some of our findings.

The survey of parasitic hymenoptera alone has shown that crop season paddy fields would be one of the typical habitats for the activity of these wasps. Although, there was not much difference in the family composition, between fallows and crop season paddy fields, a good proportion of the species (71 species) were found to be active in the cultivated paddy fields, when compared to 62 species of parasitic wasps of fallow paddy lands (The species compositional similarity of the paddy fields of these two seasons, and similarity to other uncultivated corridors are discussed in the next Chapter).

The two-fold increase in the number of individuals of parasitic wasps in the cultivated paddy fields, in comparison to the off-season fallow field, emphasizes the crucial role of hymenopteran parasitoids as natural enemies of rice pests (See Table 3.5 for statistics). The line diagram (Figure 3.8) reveals that this difference is mainly observed for members of Scelionid, Braconid, Mymarid, Eulophid, Trichogrammatid families, which were the most specious and abundant parasitic wasps in this study. If we compare the proportion of the number of individuals of these dominant families, 86 % of Trichogrammatids, 84 % of Braconids, 67 % of Eulophids, 65 % of Mymarids, and 62 % of Scelionids were found to be active in the crop season paddy fields (See Appendix I for exact figure).

50% of order Diptera is comprised of pest groups like Cecidomyids, Chironomids, and Ceratopogonids. But, some other minor pests, particularly *Hydrellia* sp. (Ephydriidae), and some species of Muscid flies etc. were not present in large numbers in the Sringeri rice paddy fields. However, predatory and parasitic flies have contributed only 11 % of the dipteran population. The dominant predatory flies of the crop season paddy fields were Dolichopodids, Empidids, Mycetophilids, Syrphids, and *Ochtera* sp. of Family Ephydriidae. Tabanids and Asilids were the abundant predatory groups of the fallow paddy lands. The major parasitoid flies were Sarcophagids, and some species of

Muscid flies. It is observed that, the impact of dipteran pests to the rice paddy saplings is marginal. Although some Ephydrid species and Chironomids were abundant as leaf miners, and root feeders, a heavy loss due to these insects has not been reported.

The systematic sampling during the present one year study period yielded 59 species of spiders from 15 families. Studies of Togashi and Taka (1988), Clausen (1987), and Young and Edwards (1990) have reported 62 species from Japan, 80 species from China, and 75 species from USA respectively, from the rice paddy lands. These results are similar to those obtained in the present study. Bambaradeniya and Edirisinghe (2001) reported 60 species of spiders from the rice paddy lands in Sri Lanka. Heong et al (1991) identified 13 families and 13 species of spiders in the Philippines rice paddy lands, and reported *Pardosa pseudoannulata* as the most abundant spider species of rice paddy lands, followed by *Tetragnatha spp.* Reddy (2000) and Venkateshalu (1996) also reported 23 and 20 species of spiders from the rice paddy fields of Bangalore and Mandya districts respectively. Sudhikumar (Personal communication) identified 80 species of spiders in the low land irrigated rice paddy fields of Kuttanad region of Kerala. *Araneus ellipticus* (Araneidae), *Tetragnatha mandibulata* (Tetragnathidae) and *Lycosa pseudoannulata* (Lycosidae) were the dominant species of Kuttanad rice paddy agro – ecosystems. 67 and 51 species of spiders were collected from two up land rice paddy fields of Kerala State in India (Sudhikumar: personal communication). In Sringeri rice paddy agro – ecosystems also Lycosidae was the most abundant family during fallow period; the findings agree with some other studies like Ansari and Pawar (1992), Reddy (2000), Venkateshalu (1996), who also reported that Lycosidae is the most abundant family of rice paddy fields during fallow period in Karnataka. Salticidae dominated other families in species richness, in the fallow land of Sringeri rice paddy agro – ecosystems in the present study. Reddy (2000) and Venkateshalu (1996) also reported a good proportion of the salticids in the rice paddy agro – ecosystems. However, a huge difference in the total number of individuals exists between Lycosidae and Salticidae in the fallow lands of Sringeri rice paddy lands; Lycosids were more than six fold the number of any other families. Meanwhile *Lycosa sp 1* alone represented > 40 % of the spiders collected in the fallow period. According to Venkateshalu (1996), two other Lycosids, *Pardosa sp.* and *Pardosa Sumatrana*, were the abundant species in the paddy

fields of Bangalore and Mandya districts of Karnataka. In the present study, these two species representation was not more than 16 %, but was the second largest species group after *Lycosa sp.*

Although, spiders are accepted as the major natural biological control agents of rice paddy agro – ecosystems in many of the rice growing areas, the generalist behavior of spiders make them one of the major intra-guild predators too, where they feed on other predatory insects. In this study a good proportion of *Oxyopes javanus* (Araneae: Oxyopidae) were found capturing several other predatory arthropods, such as damselflies, ichneumonid wasps etc. (See Plate 6). This particular species was seen in the bushes of the paddy bunds during non-crop seasons, but were found abundantly in the paddy fields during crop season. Although, the particular species was one of the intra guild predators of rice paddy fields, it was found as an active predator of several other pests, which include caterpillars of various moth pests.

The above-mentioned four orders were the most diverse arthropods of the Sringeri rice paddy agro – landscapes, which together comprise 83 % of the total population data. However, 55 % of this data was credited to the family Hymenoptera, due to the presence of Formicidae. Dipetra (24%), Coleoptera (17%), and Araneae (4%) were the other three diverse and abundant families of Sringeri landscapes. However, if abundance were the only source of interest, Homoptera and Thysanoptera would be the abundant Orders before Araneae. But, the difference was marginal (See Appendix 1). The other 14 families together explained rest of the 17 % of the population data. Family Heteroptera (34 species) and Homoptera (31 species) were the next specious families after Araneae.

Order Heteroptera was represented by a total of 804 individuals from 34 families. However, more than 90 % of the population was captured from the fallow lands, and Phytophages like a part of Lygaeida species and Pentatomid species were the abundant classes in the fallows. The Coreid population of the crop season paddy field was represented mainly by *Leptocorisa spp.* But, the crop damage due to this insect pest was very low. Heong et al (1991) reported 26 families of heteropterans, included in two different guild classes, phytophages and predators, in the Philippine lowland rice paddy lands. Apart from this, no other studies are available to compare the biodiversity of Heteroptera of rice paddy agro – ecosystems.

Order Homoptera of Sringeri rice paddy agro – landscape was dominated by Cicadellids. Three minor pests of rice paddy saplings were collected only from the crop season paddy fields. A good proportion of the total 1431 individuals were sampled from the fallows (840 individuals), and another 591 individuals were collected from the crop season paddy fields. However, more than 85 % of 591 individuals consisted of three pest species, *Deltocephalus (Recelia) dorsalis*, *N. virescens*, and *Sogatella furcifera*. The study by Heong et al. (1991) found that the proportion of homopterans of Philippine rice paddy lands varies between 55 – 80 % of the total phytophage population. They also have reported the presence of *N. virescens*, and *S. furcifera* as minor pests of paddy apart from *N. lugens* as a major pest of rice paddy saplings.

Order Thysanoptera, was represented only by three species. One species of Phlaeothripidae was identified as a dominant phytophage of rice paddy saplings. Order Orthoptera, though, richly, and abundantly represented in the fallow lands, was almost negligible in the cultivated paddy fields, apart from one species of Acrididae

3.4.2 FLORAL COMMUNITY STRUCTURE OF SRINGERI RICE PADDY AGRO - LANDSCAPES

The flora of rice paddy lands, are broadly categorized into two groups: macrophytes (all rooted, broad leaved plants), and microphytes (algae, and fungi). The present study was more centered on the macrophytes of rice paddy lands, which mainly comprise of weeds that compete with rice paddy saplings for nutrients, with their broad root network. A total of 210 species of wild flora from 66 families were identified from rice paddy agro – landscape of Sringeri. This comprised of 125 species from 32 families on paddy bunds, 72 species from 26 families on fallows, and 135 species from 51 families of the adjacent corridors. Several of the major weeds of global importance (Holm *et al.* 1977) were seen in Sringeri rice paddy agro – ecosystems too, which include *Eleusine indica*, *Cyperus difformis*, *C. rotundus*, and *C. iria*. (See Appendix II for species list and their habitat).

Grasses (Poaceae) and Sedges (Cyperaceae) dominate the rice paddy agro – ecosystems of Sringeri. Family Poaceae was the most species rich at all the three levels, fallow lands, paddy bunds, and corridor habitats (See Figure 3.9, 3.11 and 3.13). Asteracean members were more on bunds and fallows, which was immediately followed by the Cyperacean members. However inside corridors, Cyperaceae was second

dominant family after Poaceae. Present findings on the flora of Sringeri rice paddy agro – ecosystem agrees with other studies (Velmurugu 1980, Weerakoon and Gunewardena 1983, Moody 1989, Chandrasena 1987, 1988, and Senevirante et al 1992). All the studies have shown Poacean members as the dominant family in the rice paddy agro – ecosystems, with Cyperaceae being the next dominant. Moody (1989) has reported nearly 340 species of weeds in the rice paddy lands of Sri Lanka. Weerakoon and Gunewardena (1983) recorded 134 species of weeds belonging to 32 families in the rice paddy lands of Sri Lanka; subsequently Bambaradeniya (2000) reported 89 species of macrophytes in the rice paddy lands of Sri Lanka. Oudhia (1999) reported more than 50 species of weeds in the rice paddy agro – ecosystems of Chhattisgarh in India.

Most of the Asteracean members of the bunds flowered during the crop season, which served as the floral sources for a number of butterflies, which include the pest species *Pelopidas spp.* and several other adult parasitic wasps. One particular species of Balsaminaceae, *Impatiens diversifolia* was found flowering in large numbers on the bunds and floor of one of the Acacia plantation, which attracted a good number of bees and wasps in the crop season (See Plate 7). This may explain the abundance of lepidopteran and hymenopteran during crop season.

Paddy fields, though considered as a monoculture system, harbors a lot of medicinally important weeds too. Oudhia (1999) reported 35 species of weeds of rice paddy fields as medicinally important. In our study, nearly 43 species of weeds were identified as medicinally important from the rice paddy agro – ecosystems; particularly the members of families Apiaceae, Asteraceae, and Onagraceae. *Centella asiatica* (Apiaceae) was one of the abundant species in the rice paddy field, and is widely used in herbal medicines as an anti – rheumatic, anti – arthritic formulation. *Cyperus rotundus* (Cyperaceae) was the other abundant medicinal weed seen in the rice paddy fields of Sringeri. The rhizomes of this plant were rich in the flavonoids, and alkaloids, and in Pharmacology it is widely used as a remedy for hypertension, Cholesterol problem, and Diabetes. *Vitex negundo* (Verbenaceae) was the other widely located medicinal weed of paddy bunds, and other waste lands in Sringeri. The weed is particularly used in the herbal medicines aimed to reduce libido and inspire chastity, which gives it the local name Chaste tree for this plant.

3.4.3 INSECT PESTS AND THEIR ARTHROPOD NATURAL ENEMIES OF SRINGERI RICE PADDY AGRO – ECOSYSTEMS

In the present study it was observed that, although, a number of insects and other arthropods are attracted to the rice paddy fields, only very few species damage the crops extensively. This was true for several rice paddy agro – ecosystems around world (Barrion and Litsinger 1994, Pathak and Khan 1994, Dale 1994, Reissig et al. 1986, Bambaradeniya 2000). Barrion and Litsinger (1994), estimated that, only less than 20 % of all arthropods collected were identified as major crop pests for south and Southeast Asian paddy fields. Dale (1994) also reported a similar case. Pathak and Khan (1994) and Reissig et al (1986) reported 20 and 30 insects respectively as major rice paddy pests. Bambaradeniya (2000) identified only 24 species from 130 species collected in the Sri Lankan rice paddy agro – ecosystems, as major or minor pests.

In the present study, 113 phytophage insects are identified together from Kharif and Rabi season paddy fields of Sringeri area in 2003 and 2004. However, not a single major pest of rice paddy was identified for the Sringeri rice paddy agro – landscape. Although, *Leptocorisa acuta* is a well-known paddy pest for several countries, the population build up of this particular pest was relatively low in Sringeri rice paddy lands. Although, not a major pest in any of the study sites, *Nymphula depunctalis* would be one of the local ‘major’ paddy pest, which had the potential to damage rice paddy saplings, by defoliating the early vegetative stage of rice paddy saplings. This would be due to the fact that Sringeri is one of the heavy rainfall areas in south India, which would have provided a suitable microhabitat for the out break of this particular defoliator. Grist and Lever (1969) identified *N. depunctalis* as a major pest of rice paddy of water logged fields. If *Nymphula depunctalis* was the only abundant defoliator in the year 2003, *N. fluctosalis*, was also identified as a ‘local major’ pest of rice paddy saplings of Sringeri rice paddy agro - ecosystems in 2004. Although, a number of predatory arthropods were reported for this particular pest (Litsinger et al. 1990) in several rice growing countries, the discovery of *Litochila sp.* during this study (Hymenoptera: Ichneumonidae) would be the first report of a potential parasitoid for this particular pest. Although the potential of this particular pupal parasitoid was studied in the field, more data is needed to validate the observation.

The presence of a large number of parasitic hymenopterans during the crop season in rice fields of Sringeri does indicate their efficacy in keeping the population of potential pests in check. Further studies have to be carried out to confirm their efficiency as parasitoids.

The role of spiders of Sringeri rice paddy fields was restricted to the capture of the adult moths and bugs as generalist predators, rather than capturing the larval forms of these pests. *Oxyopes javanus* was an aggressive predator of several adult moth pests, especially *N. depunctalis*, *N. fluctosalis*, and *C. medinalis*. The other major predators of the adult Pyralid, and Pierid pests were damselflies (Odonata: Coenagrionidae) of two unidentified species. The observations do suggest that spiders have a limited role as predators in rice paddy agro – ecosystems. Although a detailed study of microbial biocontrol agents of rice paddy pests has not been carried out in the present study, while doing survey a number of *Spodoptera sp.*, and *M. leda* larvae were found dead due to the suspected role of microbes. Singh & Murthy (2002) reviewed the works on biological control of rice paddy pests in India till 2002. See Appendix I for the whole species list of parasitoids, pests, and other major predators, such as spiders.

Apart from the above-mentioned arthropod pests, two other ‘major’ pests of rice paddy agro – ecosystem of Sringeri were two species of crab and one species of a land snail. Grist and Lever (1969), and Chatterjee and Dutta (1980) also reported the crab menace in the rice paddy agro – ecosystems in several parts of the rice growing countries. The pattern of damage due to these two species of crabs was different in the rice paddy fields; one species of crab (probably *Paratelphusa sp.* and locally called as *Belledi* (= white crabs), which is small in size, and was purely phytophagous, attacked the rice paddy seedlings of the paddy nursery and also the early transplanted saplings. The damage due to this particular species was tremendous as they cut down the propagules of the seedlings, which checked the further growth of the seedlings. Some of the farmers were using Timmet to eradicate the crab menace from paddy fields; however this particular pesticide had a detrimental impact on the rice ecosystems, as it destroys all the biota of the ecosystem. But some farmers removed the crabs by mechanical means. The other species of crab, which is slightly bigger in size, which also was found abundantly in the Areca orchards of Sringeri, causes the damage mainly by digging holes in the paddy bunds, and thereby affecting the irrigation system. Naylor (1996) reported the invasion of

the golden apple snail to the rice paddy fields of Asia. But in the present study, apple snail (*Pomacea sp*) infection was found restricted to four of my study sites, where it was found very commonly in the paddy field during the early vegetative phase, however, the damage was not severe. Surprisingly, the farmers were not even aware of the role of these snails in the paddy fields.

3.4.4. SOIL VARIABLES OF SRINGERI RICE PADDY AGRO - LANDSCAPE

Although the chemistry of the rice paddy soil of Sringeri region was almost similar for all of the 21 study sites (Figure 3.14 – 3.16), a significant difference in the percent Organic Carbon and Average Phosphate content of the soil between study sites would be attributable to the agronomic practices, rather than any other natural parameters. Increase in the Organic Carbon content of the soil was mainly due to the increased use of Organic compost in the paddy fields, and the difference in the Phosphate content would be attributable to the difference in the amount of inorganic fertilizer application by the farmers. Soil of DS (among corridors) and DSPaddy (among paddy fields), were more or less equally rich in OC, rather than any other treatments. This relative increase in the percent of OC in the paddy fields adjacent to heterogeneous land use corridors, such as degraded scrubs (DSPaddy), and Soppinabetta forests (SBPaddy), rather than other two simplified land use types would be due to the wash off of nutrient rich top soil from these diversified land use types to the paddy fields during rainy days.

3.4.5. SPECIES ACCUMULATION CURVE

Results show that the arthropod community of the rice paddy agro – landscapes of Sringeri was very diverse and species rich, like other tropical Asian agro – ecosystems (Bamabaradeniya 2000, Barrion and Litsinger 1994). The results also show that arthropod community of Sringeri landscape is yet to be fully sampled. Although we expected that the species accumulation curve for the arthropod community of the rice paddy agro – ecosystems might reach the asymptote, due to a considerably long sampling regime with all sampling methods, the curves did not attain the asymptote. The results on the floral community of Sringeri rice paddy agro – ecosystems clearly shows that the present sampling regime was enough to capture the diverse floral community

composition of the rice paddy lands; as the curves for both fallow lands, and paddy bunds reached the asymptote. The study also shows that the present number of quadrates was not enough to sample the entire lower strata vegetation of the corridors.

3.4.6 CONCLUSION

Rice cultivation is considered to be one of the oldest, or probably the first form of intensive agriculture by man. The rice agro – ecosystem is not a simple or intensive monoculture habitat; a number of wild relatives depend on this unique ecosystem, and enriches the biodiversity value of it, when compared to any of the other monoculture cereal farmlands. This study reveals that more than 800 species of arthropods enjoy the benefits of rice paddy agro – ecosystem for various purposes, either in the fallow lands or in the crop season paddy fields. Although 113 species of insects were assigned as the phytophages of this particular ecosystem, only less than 10 % of this was assigned as pests of paddy plants. The study concludes that the small, and less intensive rice paddy agro – ecosystems, particularly the one seen in the uplands, are an integral part of the nature, where a harmony between people and nature exists. However, a number of recent developments threaten the biodiversity values of this unique agro – ecosystem, especially the upland rice paddy lands.

Chapter 4

IMPACT OF STAND SIMPLIFICATION IN THE ADJACENT UNCULTIVATED LANDS ON INSECT PESTS AND ARTHROPOD NATURAL ENEMIES OF RICE PADDY AGRO-ECOSYSTEMS: TESTING NATURAL ENEMY HYPOTHESIS

4.1 INTRODUCTION

Traditional farming systems using the locally available resources, experimental knowledge, and self-reliance have been established centuries back in the developing countries. Peasants following traditional farming system usually utilize, maintain, and preserve natural habitats of various shapes, and kinds that vary from hedges to forests, adjacent to their farms, which contribute valuable food supplements, organic fertilizers, and medicines to the farmer (Toledo 1980). Added to it, the farmers also benefited from the natural control of their agricultural pests by a number of predatory and parasitic fauna that were supported by these wild ecosystems. Habitat heterogeneity is not only important for the resource availability and flora and fauna conservation, but also help to reduce the pest problems in the agricultural fields (Altieri 1983, Ekbom 2000). However, in the modern farming systems, which is also seen in the developing countries, the importance of maintaining the heterogeneity of the adjacent uncultivated lands is often

overlooked, where intensive farming practices often simplified the agricultural landscapes, and more importance was given to increase the production (Altieri et al. 1987).

The future of nature is at high risk due to increasing food demand, which is predicted to double by 2050. The threat will affect developing countries more (that harbors most of the species), as the area of cropland and pastures has increased by more than 20 % from 1961 to 2000, while it has shrunk in developed countries (Green et al. 2005). This has resulted in wildlife friendly farming practices, primarily by preserving the remaining fragmented wild habitats adjacent to croplands and pastures in order to enhance the population densities of wild flora and fauna. These practices are gaining popularity in developed countries.

4.1.1 AGRO-ECOSYSTEM APPROACH TO AGRO-LANDSCAPES LEVEL

Tropical landscape mainly comprises of agro-ecosystems, and the natural habitats like forestlands and other woodlands are embedded in the agricultural landscape, which together form an *agro landscape* (Laurance and Bierregaard 1997), and it is a general belief that the dispersal or migration of potential bio control agents happens from the adjacent natural habitats during the cultivation time.

Biodiversity contributes a lot to pest control (Schlapfer *et al.* 1999), and the studies during past one or two decades emphasized the need for conserving this biological diversity in agro-ecosystems. The twentieth century witnessed several changes in agricultural practices. Among these the most noticeable and serious changes were homogenization of agricultural landscapes and isolation and fragmentation of summer or winter refugia that lead to the decreased biodiversity and increased pest problems (Naylor and Ehrlich 1997). Intensification of farming practices and abandonment of farmlands are identified as other noticeable changes during this period, and relatively less information is available on how the changing agricultural practices affect the ecosystem processes and functions by affecting the biodiversity (Wilby and Thomas 2002).

Traditionally, a single field (monoculture agro- ecosystems) was selected to address major problems related to IPM, restoring biodiversity, or improving crop productivity (Barrett, 2000); however, 21st century began with an *agro-landscape*

approach, in which several landscape elements like fragments, patches (land use changes) and corridors serve major roles apart from the heterogeneous field boundaries and bunds, in finding answers related to IPM, nutrient restoration, trophic and biotic diversity and primary productivity in agricultural lands. Spatially and temporally, these *agro-landscapes* that comprise of heterogeneous field boundaries, hedgerows, and adjacent uncultivated heterogeneous lands have an impact on beneficial predatory and other natural enemy species richness, distribution and density (Barrett, 1992).

4.1.2 IMPACT OF LAND USE CORRIDORS ON ARTHROPOD ASSEMBLAGES IN AGRO-LANDSCAPES

Increasing vegetational diversity within agricultural lands and surrounding landscapes enhance the population density of insect natural enemies of various pests (Kemp and Barret 1989, Andow 1991) that helps to reduce unscientific application of inorganic fertilizers and pesticides. This ultimately assures a natural balance in agro-ecosystems. Farm manipulation by intra and inter cropping systems and management of adjacent non-crop field boundaries, cause a decrease in pest populations (Speight and Lawton 1976, Risch et al. 1983, Coaker 1990, Nentwig 1989). However, most of the hedgerows and field bund structures that remain have become degraded due to modern farming practices, such as intensive ploughing very close to the bunds or careless and unscientific application of a wide range of herbicides and fertilizers at the field margin. Year round weed removal as part of farming intensification (Davies and Dunford 1962) also have resulted in the degradation of the field bunds by removing a major portion of flowering grasses and other medicinal herbs that serve as over wintering as well as feeding habitats for several of the insect natural enemies. But, the importance of field boundaries and uncultivated lands adjacent to monoculture farms has been recognized during the last one decade (Boatman 1992, Bryan and Wratten 1984, Bultman and Uetz 1982, Carmona and Landis 1999, Dennis and Wratten 1991, Desender 1982, Helenius 1995, Robinson 1981, Thomas et al. 1991 & 1992, Price 1984, Hassell 1978). Most of these studies were done in simulated, experimental *agro-landscapes*, before implementing the findings in a spatial scale (Barrett 2000). Two such important simulated experimental *agro-landscapes* are the heterogeneous 'island' habitats (Thomas et al. 1991) and 'beetle banks' (Chiverton 1989, Collins et al. 2002) that are created mainly to conserve the beneficial polyphagous

predatory arthropods like Carabidae, Staphylinidae, and Araneae inside agricultural lands across the world. Both *island habitats* and *beetle banks* were created by planting several grass and other herbs in linear raised strips, which eventually criss-cross the entire farmland (Thomas et al. 1992).

Island habitats and *Beetle banks* provide conservation sites within the agricultural landscape, promote biodiversity, and enhance populations of natural enemies to increase their pest control function (Thomas et al. 1992, MacLeod et al. 2004). Other than providing a niche for over wintering insect predators and other natural enemies, these habitats also provide nesting sites and perching sites for predatory birds and sometimes they even serve as the corridors for insect dispersal and migrations (Thomas et al. 2000; Thomas et al. 2001). In several countries and geographical regions *Beetle banks* have contributed a useful habitat resource for several of the polyphagous insect predator populations (Carmona and Landis 1999, Berry 1997, Chiverton 1989).

4.1.2.1 *Natural Patches, Fragments, and Corridors in an agro-landscape*

Similar to the changes in approaches from agro-ecosystems to agro-landscape in 21st century, the understanding on arthropod patterns also has changed from the mere estimation of arthropod abundance in agro-ecosystems to arthropod movement and dispersal in and outside the agricultural field (Barrett 1992, Barrett et al. 1997). This has helped to evolve a new strategy- an *integrated agro-ecosystem management* (El Titi and Landes 1990) coupled with an *agro-landscape*- in the integrated pest management (IPM) methods. Several studies have established the importance of the agro-landscape approach - the mosaic of agro-ecosystem wedges with the forest fragments, in finding out solutions for insect pest control; in an example, Mexican bean beetle, *Epilachna varivestis*, used the forest lands and woodlands as the winter refuge (Kogan and Kuhlman 1982). Indeed, studies on the dispersal and movement pattern of insect pests and their arthropod natural enemies in these agro-landscapes are still a novel topic, which need to be explored more.

The natural enemy movement and colonization, like pest movement, in simple and diverse habitats also have gained international prominence in the beginning of the 21st century. This has resulted in formulation of two major hypotheses- *natural enemy hypothesis* and *resource concentration hypothesis*- towards the theme 'conservation biological control'. As mentioned before, most of the field tests, which are also reviewed

below in this Chapter are tested in the small experimental plots, and restricted mostly to the temperate and developed countries. The meaningful extrapolation of these results and findings to a large area and generalization of particular study results to all agro-ecosystems are still a matter of debate now.

4.1.3 NATURAL ENEMY HYPOTHESIS VS. RESOURCE CONCENTRATION HYPOTHESIS, AND ITS IMPLICATIONS IN AGRO-LANDSCAPES

Natural Enemy hypothesis predicts that plant species-rich land-use systems support many arthropod predators and parasitoids, primarily through providing alternate hosts (Root 1973), suitable microclimate (Risch 1981), and also by rendering the varied nectar sources for adult natural enemies (Root 1973, Leius 1967), and that ultimately control herbivore populations. *Resource concentration hypothesis* suggests that higher abundance of herbivores in monoculture systems are mainly due to the fact that the herbivores can find more food resource in a short space of time, to maintain higher feeding rates and fast multiplication, with less number of natural enemies (Root 1973). While studying enemy hypothesis in experimental and natural landscapes, most of the investigators concentrated on estimating the density of natural enemies in simple and diverse agro – landscapes (Root 1973, Bach 1980, Risch, 1981, Pimental 1961, Riechart and Bishop 1990), and only a few studies have compared the predation and parasitism rate between simple and diverse habitats (Root 1973, Andow and Risch 1985, Speight and Lawton, 1976, Letourneau 1986 and 1987, Marino and Landis 1996, Menalled *et al.* 1999). While the studies on Resource concentration hypothesis proved that the variation in the herbivores' response to habitat diversification is totally species dependant and the rule cannot be generalized (Kareiva 1983, Andow 1983 & 1991). Rather than contradictory, both these advanced hypotheses are mutually exclusive and complementary to each other. However Risch *et al.* (1983) exemplified that movement pattern of herbivores is accounted in most cases as the major reason for the pest outbreak in simple than diverse system, rather than the actions of natural enemies. Whilst, Bhatnagar and Davies (1982) explicitly showed that both the pest movement and natural enemies are equally important in determining pest abundance pattern. Root's (1973) study results stimulated several other investigators to test these hypotheses in different agro-ecosystems and landscapes in various parts of the world.

For the past two decades several studies have analyzed the importance of uncultivated natural habitats in supporting the polyphagous predatory arthropods. Risch *et al.* (1983) and van Emden (1990) have demonstrated the importance of maintaining the 'structural diversity' in agro-ecosystems in order to reduce pest attack. In a study, Bishop & Riechert (1990) showed that spiders from the adjacent abandoned fields may migrate into the cultivated vegetable gardens if both lands are similar physiognomically, and indicated that the spider immigration into cultivated lands from the neighboring natural habitats does not happen. Luczak (1979) reported that some spiders over winter in the agricultural lands itself, and stated that if spider immigration happens into the cultivated lands, it is totally dependant on the dispersal capability of individual species and the proximal natural habitats can act as the natural reservoirs for those spiders. Furthermore, spiders and Carabid beetles are known to be the pioneers of any habitat due to their high dispersal capability (Southwood 1962). Riechart and Bishop (1990) later emphasized that maintaining the 'habitat structure within agro-ecosystems' is more important for conserving the spiders in local area than maintenance of natural reservoirs.

4.1.3.1 APPLICATION OF NATURAL ENEMY HYPOTHESIS WITHIN AGRO-ECOSYSTEMS

Russell (1989) reviewed 18 studies, which tested natural enemy hypothesis in various agro-ecosystems in a time frame, and found that natural enemy caused mortality of the targeted pest species is more in diverse habitats rather than the simple ones. However, it is well proved in several ecosystems that the increased prey diversity explicitly stabilizes the predator populations and it is well demonstrated in the agricultural landscapes too (Pimental 1961, van Emden and Williams 1974, Murdoch, 1975).

Risch *et al.* (1983) examined 150 published studies that tested the impact of diversifying the agro-ecosystems on herbivore status, and noted that nearly 53 % of the herbivores were found to be less abundant in the complex habitats compared to the simple monocultures, Furthermore, 18 % of the herbivores observed in the studies were found to be abundant in the polycultures, and for 9 % of the herbivores, no difference in the population was accounted for between diverse and monocultures.

Root (1973) has mentioned several mechanisms, which underpin the natural enemies hypothesis. The major ones include: (1) the complex agricultural systems

provide diverse range of hosts and microclimate for the existence of the natural enemies, (2) this then lead to stability in the predator prey populations, (3) the diverse habitats also provide the refuge for the host organisms during the off season, which helps to avoid extinction of both the host and specialist natural enemies, particularly parasitoids, and (4) the diverse habitats provide continuous supply of nectar and reproductive sites, and over winter refuges for the natural enemies. Root (1973) also has mentioned the role of the natural enemies in the fourth trophic level, i.e. predators predate on other natural enemies, and parasitoids hyperparasitise on other parasitoids. Although they have high relevance in biological control, their effect in the field has seldom been tested (Doutt *et al.* 1976). Interestingly, a new theme called Intra Guild Predation (IGP) has been developed recently (Polis *et al.* 1989) in conservation biological control.

which are
predators
prey
parasitoids
hyperparasitoids

Letourneau (1986), compared three kinds of agro-ecosystems, Squash monoculture, Maize monoculture, and a triculture (squash, maize, and cowpea), and endorsed the natural enemy hypothesis, as he identified Squash monocultures, as the least diverse with respect to parasitoids. However, the Maize monoculture was found equivalent to triculture and the greater number of parasitoids and richness in triculture is accounted more due to the presence of Maize, rather than the diversity per se. But, he concluded that increased vegetational association enhances the natural enemy build up and rate of parasitisation of army worm, *Pseudaletia unipuncta* in Maize. Marino and Landis (1996) also demonstrated a significant positive impact in the parasitoid diversity and rate of parasitism of army worm, *Pseudaletia unipuncta* in Maize crop in complex landscapes (Maize intermixed with non crop woods) compared to simple (only Maize crop) landscape. Menalled *et al.* (1999), concluded that landscape complexity does not have any role in determining the parasitoid diversity and rate of parasitism, as he found a good number of parasitoids in simple than complex Maize crop.

Herbivore accumulation in resource concentrated habitats is also attributed due to less amount of natural enemy build up in simple habitats (Root 1973). Coll and Bottrell (1994) studied the bean beetle (*Epilachna varivestis*) population in varying degree of monoculture cultivation and two sorts of dicultures (mixed with short & tall *Zea mays*), and observed no significant difference in the bean beetle population between high and low intensive bean monocultures, and short corn mixed dicultures. However, a

remarkable difference was noted in bean beetle population infesting tall corn and the other experimental habitats. The study concluded that the relative low number of beetles in diculture is more due to the effect of tall corn, rather than plant diversity. The study also found that tall *Zea mays* increased the suitability of the host plant (beans) to attract the adult and larvae of beetle primarily by providing healthy, broad leaved beans (that slightly contradict the resource concentration hypothesis). Coll & Bottrell (1994) also found no significant difference in the larval mortality of beetles between mono and dicultures, disapproving the role of natural enemy hypothesis.

A number of studies investigated the pattern of distribution, and density of various beneficial arthropods with distance from farm boundary towards interior (Kemp and Barrett 1989, McLachlan and Wratten 2003, Luff *et al.* 1989, Bishop and Riechert 1990). McLachlan and Wratten (2003) showed that density and species composition of spiders declined rapidly with distance from the pasture edge during uncultivated season, and also reported a considerable turn over in species composition between shelterbelts (abandoned land) and pastureland. The study also predicts that shelterbelt habitat may act as the off-season refugia for the spiders that disperse in pasture lands later in crop season.

Andow (1990) compared the bean beetle population in four agro – landscapes – bean monoculture, bean-mustard diculture and two bean-weed mixtures, and noted that there was relatively lower adult beetle colonization and egg survival in bean-weed cultures, and was highest in bean monocultures; which confirms both the hypotheses. But, the relative lower larval / pupal mortality in weed mixed diculture has contradicted the predictions of enemy hypothesis and concluded that non-host plants in polycultures, rather than natural enemy populations decreased the immigration of pest populations. In another study, Speight & Lawton (1976) found an increased rate of predation by a carabid beetle, *Pterostichus melanarius* on cereal pests in weed covered diverse habitats compared to simple monocultures. aut

In most studies the parasitism and predation rate are assessed only for a particular life stage of the pest species. Apart from studying the rate of colonization of adult herbivores (as part of resource concentration hypothesis) in various habitats, studies have not revealed a greater predation or parasitism rate of adult herbivore populations. Risch

(1981) and Bach (1980, 1984) reported that the effect of natural enemies on adult cucumber beetles was low, and similar between simple and diverse habitats.

Unlike enemy – herbivore response studies, enemy – vegetation structure relationship is less documented (Sheehan 1986), and it is more evident in several parasitoid - host relationships. The specialist natural enemies respond almost in similar way as that of herbivores, which are expected to concentrate in resource rich plantations. For specialist natural enemies, their specific herbivorous hosts are the major breeding resources and they are expected to be more in monocultures rather than diverse habitats. From the above reviewed papers, it is clear that habitat diversification is more favorable to generalist natural enemies, mostly for polyphagous predatory arthropods. Very few studies (Sheehan 1986; Russell 1989; Coll and Bottrell 1996) have followed the impact of habitat diversification on specific natural enemies. Sheehan (1986) illustrated that specialist natural enemies' response to the vegetational structure is just opposite to generalists', and found a good number of specialist natural enemies in simple than diverse habitats. In many cases, generalist enemies are mentioned more, in the discussions of the natural enemy hypothesis. However, from the view of yield and pest control, specialist natural enemies succeeded in pest suppression more than generalists (Beddington *et al.* 1978, Hall *et al.* 1980). Very surprisingly, there are only few studies on the impact of habitat diversification on specialist natural enemies. In another study, Smith (1976) found a four fold higher parasitism in the tilled monoculture Brussels sprouts compared to the weedy plots. In another instance, Richards (1940) reared the specialist natural enemies of *Pieris rapae* (L) only from the uniform cabbage plots. Furthermore, both the above-mentioned studies brought out an estimate of an equal number of generalist parasitoids from simple and diverse habitats. Coll and Bottrell (1996) after an experimental observation on a specialist parasitoid, *Pediobius foveolatus* of Mexican bean beetle in mono and diverse habitats (with Maize), concluded that the female parasitoids were more in the monoculture bean fields rather than any of the other diverse fields. The study further revealed the importance of another parameter, such as the height of the Maize plants, rather than the diversity per se, that caused the reduction of the female wasp's immigration. Furthermore, in experiments, where the female wasps

were released outside the plots, more parasitisation was encountered in the monoculture bean plantations due to their movement towards the monocultures.

Costello & Daane (1998) compared the influence of grassy cover on the species richness and abundance of spiders in vineyard. The study reported a marginal movement of spiders from the grassy floor to the vines, and found no significant difference either in species observed or abundance of spiders on vines in treatments only with vines, and the one with grassy floor. In another study Horn (1981) reported that population out break of aphid pests of collards in contiguous fields compared to the weed mixed collard fields, supported the resource concentration hypothesis. However, a large number of generalist predators were eventually found having moved towards the contiguous collards, when the weeds were trimmed in the weed mixed collard fields.

4.1.3.2 Application of Natural enemy hypothesis in Agro-landscapes

Most of the above reviewed works concentrated more on the impact of within cropland diversity on beneficial arthropods, and in contrast to that, only very few studies explored the importance of uncultivated heterogeneous natural corridor habitats in landscape level. Kemp & Barrett (1989) may be the pioneers of this type of studies. Their study in soybean fields explored all the three relevant levels - natural enemy density, crop damage, and crop yield. As this study influenced most of the present study objectives, a detailed account of their findings deserve mention here. The study compared soybean fields experimentally manipulated in four different ways- wild succession into the field from uncultivated corridor (S), artificially planted heterogeneous grassy succession into the field from the corridor (G), control without any succession (C), and insecticide sprayed control (I). The pattern of crop yield showed that yield was highest in I and was lowest in S and G. The leaf damage by the defoliators and all other kinds of herbivory also gave a similar result. The above ground predators were abundant in the uncultivated corridors and were few in number in all soybean fields, and were more in C than S and G while studying across treatments. But, a fungal pathogen known to be the natural control agent of all lepidopteran pests of soybean were encountered more in S and G, compared to C and I. It was revealed that the uncultivated corridor could be the reservoirs of these Fungi. The study also argued that no significant difference in damage and pest

colonization occurred as distance increased from the corridors. Although, the study partially support the natural enemy hypothesis, the significant loss of yield due to weeds, and increased herbivore attack, appeal for more management in the uncultivated corridor to enhance the productivity.

Movement pattern of natural enemies are more important for their colonization of vegetationally diverse habitats, and this pattern varies from species to species. Corbett & Plant (1993) with their mathematical simulation model suggests that the inter-planted vegetation could either act as a source (happens when natural enemies colonize well before the crop germination) or sink (happens when both inter-planted vegetation and crop germinate together) for natural enemies. As mentioned before, most of these kinds of studies were undertaken in small-scale experimental plots, and the mobility of natural enemies cannot be fully assessed in these kinds of laboratory set ups.

Ogol *et al.* (1998) in another field observation in Maize-Leucaena agroforestry system found out a relatively good rate of parasitism on eggs of maize stem borers in the monoculture Maize plots rather than the Leucaena mixed maize plots. The predation rate of the stem borer egg masses also was not influenced by the intermixed habitat, and apparently was more in the Maize monoculture. The results again showed that the natural enemy hypothesis was not working in this system too.

Even though a number of studies discussed the importance of vegetational diversity within and surrounding agro – landscapes in maintaining the natural enemy abundance and species richness, very few studies have looked into the underlying mechanism. Root (1973), Vandermeer (1990) showed that wild flora adjacent to the cultivated lands render a suitable microclimate condition for the existence of these natural enemies during the off-season. Vandermeer (1990), Leius (1967), Shahjahan (1974), and Syme (1975) found that wild nectar sources also enhance the longevity and reproductive capabilities of these natural enemies apart from providing continuous food source for the adult parasitoids. This is well proved by classical laboratory experiments of several workers, such as Walcott (1942), Schneider (1953), and Simmonds (1959). Altieri *et al.* 1987, and Potting *et al.* (1995), after their experimental tests revealed that the chemical cues released from the associated plants also enhance the effectiveness of natural enemies' performance in the cultivated lands. Leius (1967) also found that all pupal,

larval, and egg parasitism rate in the grass rich apple orchards were several times higher than the grass poor orchards.

Corbett & Rosenheim (1996) convincingly argued the role of over wintering refuges in maintaining insect parasitoid populations. In their study in vineyard agro-landscapes, the authors established the role of French prune trees to supply the alternate host organisms (plant hoppers) uninterruptedly during the off season to maintain the population of *Anagrus* parasitoids of grape leafhoppers for the next grapevine cultivation. Furthermore Murphy (1994) also reported a considerable rate of hopper egg parasitism in the vineyard with prune trees as a hedge tree, compared to grapevine monocultures.

4.1.4 Objectives of the study

The study investigates the influence of various land use changes on insect pest and arthropod natural enemy population build-up^{me} in rice paddy agro – ecosystems of Sringeri. Specifically the study attempts to answer following questions: 1) how the stand simplification in the adjacent uncultivated lands or corridors affects the arthropod and flora community composition, and productivity / yield of the rice paddy lands? 2) Impact of distance gradient on arthropods, specifically spiders, Carabid beetles, and a local major paddy pest, *Cnaphalocrocis medinalis*, and productivity of rice paddy agro – ecosystem 3) What would be the proportion of arthropod, particularly predator, parasitoid, and pest, community compositional similarity between adjacent uncultivated land use types and paddy fields? 4) What are the parameters, which determine arthropod community abundance, specifically spiders, Carabid beetles, parasitoids, and *C. medinalis* larval abundance and infestation rate, in rice paddy agro – ecosystems of Sringeri?

4.2 METHODS

4.2.1 STUDY SITES

The study was carried out in agro-landscapes of Sringeri and Thirthahalli taluks of Chikmagalur and Shimoga districts of Karnataka State (See location Map in Fig 3.1, Chapter 3). The altitude of the study sites ranged between 622 – 657 m. Four land use types, categorized mainly by the stand composition, were selected for the present study. The heterogeneity rank of land use types in terms of tree as well as lower strata flora

species richness in descending order would be *Soppinabetta* forests (SB) > Degraded Scrub forest (DS) > Areca orchards (AR) > and Acacia plantations (AC). Paddy fields adjacent to each one of these four land use corridors were selected for the comparison.

21 study locations as showed in the map (Figure 3.1) were selected, where in five study sites (paddy fields) were close to *Soppinabetta* forest of almost similar physical characteristics; for other six study sites Areca orchards, having similar crop varieties and ground flora were considered as the corridor type; in the other five study sites Degraded *Soppinabetta* lands were the adjacent land use type; and in 4 study sites Acacia plantations of either one of the two species, *auriculiformis* or *mangium* were the adjacent land use types. The age, area and above ground flora, were studied in detail (See Plate 2 for images of the paddy fields adjacent to four land use corridor habitats). Areca orchards selected for this study had an area ranging from 1.5 – 6 acres, and the palms were in the age group between 14-70 years. The area of Acacia plantations was between 4 – 8 acres with an average area of 6 acres.

4.2.2 ARTHROPOD FAUNA AND FLORA SAMPLING

The above ground and aerial arthropods, flora and soil of fallows, crop season paddy fields, and adjacent land use types were sampled using appropriate techniques as elaborated in Chapter 3.

4.2.3 RICE PRODUCTIVITY ESTIMATION

Productivity of rice was estimated in two ways: by direct count of grains per earhill, and weighing the fresh weight of grains per sq m. In the first method, one week before harvesting, five earhills were randomly selected each at 0 m, 50 m and 100 m away from the interface between rice paddy lands and adjacent land use types. The chaffy grains were counted separately, which provided the *Leptocorisa* infestation rate. While in the second method, during or just before harvesting, rice paddy plants from quadrates of 1 X 1 m, each from three distance levels (0, 50 and 100m) were chopped down and whole grains were removed and the fresh grains were weighed using a balance.

4.2.4. STATISTICAL ANALYSIS

Species richness and abundance were considered as the measures of species diversity. Species richness is the absolute number of species in a particular sample, and was the

what earhills?

?

?

not necessary

principal variable of interest. Species abundance, and estimated species diversity (Shannon-Weiner index) were the other fundamental parameters of interest for the significance tests. The following part of this session provides a brief description of the statistical methods adapted for each objective of this study.

This Shannon diversity index (Magurran 1988) assumes that individuals are randomly sampled from an 'infinitely large' population (Pielou 1975). It also assumes that all species are represented in the sample. The index calculates the diversity by an equation:

$$H' = - \sum p_i \ln p_i$$

where p_i is the proportion of individuals found in the i th species, and proportional abundance of i th species can be calculated by $p_i = (n_i / N)$, where n_i is the number of individuals of i th species, and N is the total number of samples. This diversity index is highly sensitive to the rare species, which predominate in insect biodiversity studies.

Kruskal Wallis rank ANOVA was used to compare and identify the significant difference in the median species richness and abundance of arthropods between paddy fields adjacent to four land use types. Prior to that, comparison of arthropod diversity between landuse corridor habitats was also conducted. Mann-Whitney U test was used to compare species richness and abundance of arthropods along a distance gradient (mainly 50 m and 100 m away from edge). Jaccard's similarity index (Pielou 1975) was used to study the proportion of arthropods shared between adjacent land use types and paddy fields. The cluster diagram was constructed for both off-season fallows and for crop season paddy fields too.

$$\text{Jaccard } C_j = j / (a + b - j),$$

Where j , is the number of species found in both sites and a , is the number of species in site A, and b , is the number of species in site B. The similarity will be represented as a cluster diagram or dendrogram on a scale of 0 – 1, and if the sites cluster near 1, it shows they are more similar, and if it is 0, they are highly dissimilar, and have no species in common. Cluster diagram for total arthropods and separate guilds like predators parasitoids, and pests were constructed separately.

Spearman rank order correlation was used to estimate the statistical significance, and percent of relationship of microclimate, and vegetational parameters and arthropod composition in rice paddy agro – ecosystems. Step-wise multiple linear regression analysis was conducted to scoop out the best combination of variables as predictors of flora and arthropod community structure inside paddy fields. The *coefficient of determination* (r^2) suggests the proportion of the variability in the y observations that can be accounted for by variability in the x observations. One-way ANOVA was used to test the significance of the slope of the line, or the regression. Significance in the Beta values was compared by t test.

To compare the difference in the productivity of rice, which was generated by count of grains, and fresh weight of the grains, between paddy fields adjacent to four land use types, and between distance gradients, Kruskal Wallis rank ANOVA was used. The difference in the *Leptocorisa* infested grains were also compared by Kruskal Wallis rank ANOVA for the statistical significance.

Statistical Analysis was conducted using Statistica Program 3.0 (Stawin), Splus 2000, and Biodiv 4.0 program.

4.3 RESULTS

4.3.1 HOW STAND SIMPLIFICATION IN ADJACENT UNCULTIVATED LANDS AFFECT ARTHROPOD & FLORA COMMUNITY AND PRODUCTIVITY OF SRINGERI RICE PADDY AGRO – LANDSCAPES

4.3.1.1 *Comparison of arthropod diversity between land use corridor habitats*

Species richness of degraded scrub forest (DS) was the highest but abundance was the lowest. However, the difference between *Soppinabetta* (SB) forests and DS was marginal, and there was only a difference of 9 species. But, SB was most diverse considering the abundance of arthropods. Shannon index has shown that DS was more diverse followed by Areca orchards (AR). Acacia plantation had the lowest species richness and species diversity of arthropod community. See Table 4.1.

Kruskal Wallis rank ANOVA results for the whole off-season data showed that the difference in arthropod abundance between land use types was not significant, but when species richness was considered it was slightly significant ($H(df\ 3, N\ 77) = 6.60, P = 0.08$).

Table 4.1 Comparison of arthropod diversity between land use types in Sringeri rice paddy agro – landscapes

Land use	Order	Family	Species	Shannon	Individuals
SB	15	90	213	2.5	3228
DS	14	74	222	3.9	2052
AR	13	85	198	3.3	2480
AC	12	57	127	1.7	2911

The results on arthropod diversity in different land use types varied with the method of sampling. The results of pitfall sampling showed that ground arthropod species richness between land use types was significantly different ($H (df 3, N 21) = 13.10, P = 0.004$); but the difference in abundance remained insignificant ($H (df 3, N 21) = 1.56, P = 0.66$). In all out search data, the difference in both species richness and abundance of ground dwelling arthropods between land use types was insignificant at $H (df 3, N = 20) = 1.63, P = 0.65$, and $H (df 3, N=20) = 0.43, P = 0.93$ respectively.

When sweep sampling data was considered, both the species richness ($H (df 3, N 19) = 8.69 P = 0.03$) and abundance ($H (df 3, N 19) = 12.80, P = 0.005$) of arthropods was significantly different between land use types. But, the result of malaise sampling indicated that the difference was insignificant, $H (df 3, N= 17) = 5.55, P = 0.13$; $H (df 3, N= 17) = 4.44, P = 0.2176$ for species richness and abundance respectively.

4.3.1.2 COMPARISON OF ARTHROPOD AND FLORA DIVERSITY OF FALLOW LANDS ADJACENT TO FOUR LAND USE TYPES

Species richness, total number of individuals and species diversity (Shannon index) of arthropods collected using all sampling methods except Malaise was estimated for the off-season fallow lands located near four land use types. The hypothesis was, all diversity measures of arthropods would be more in the fallows that were located near *Soppinabetta* forests, and the one close to Acacia plantations would be least diverse on all diversity parameters. The results have proved the hypothesis to a certain extent; Paddy fields adjacent to *Soppinabetta* forests (SBPaddy) were the most diverse on species richness and abundance on all sampling methods, and the one close to Acacia plantations (ACPaddy) was least diverse (Figure 4.1). The relative increase in species richness and abundance of arthropods in fallow lands adjacent to Areca orchards (ARRich and ARAbun), when compared to Degraded Scrub (DS) – paddy agro – landscape is

attributed to the matching high floral diversity of fallows near AR orchards than the fallows adjacent to DS. Furthermore, species diversity on Shannon index also gave similar results; fallow lands adjacent to SB were more diverse, and the one close to Acacia plantation was least diverse on aerial arthropods, which was collected by sweeping. But, the ground arthropods were more diverse in the fallows adjacent to AR orchard and DS forest.

But, Kruskal Wallis rank ANOVA showed that the difference in the median species richness and number of individuals of ground arthropods of fallows adjacent to four land use types was highly insignificant; KW H ($df\ 3, N\ 42$) = 0.15, $P = 0.98$; H ($df\ 3, N\ 42$) = 2.19, $P = 0.53$, and H ($df\ 3, N\ 41$) = 1.83, $P = 0.60$; H ($df\ 3, N\ 41$) = 2.79, $P = 0.42$ for arthropod species richness and abundance using pitfall and all out search method respectively. However, the difference in species richness KW H ($df\ 3, N\ 40$) = 4.87, $P = 0.18$, and abundance H ($df\ 3, N\ 40$) = 4.45, $P = 0.21$ of aerial arthropods (sweep data) of fallow lands adjacent to four land use types was found to be slightly significant (See

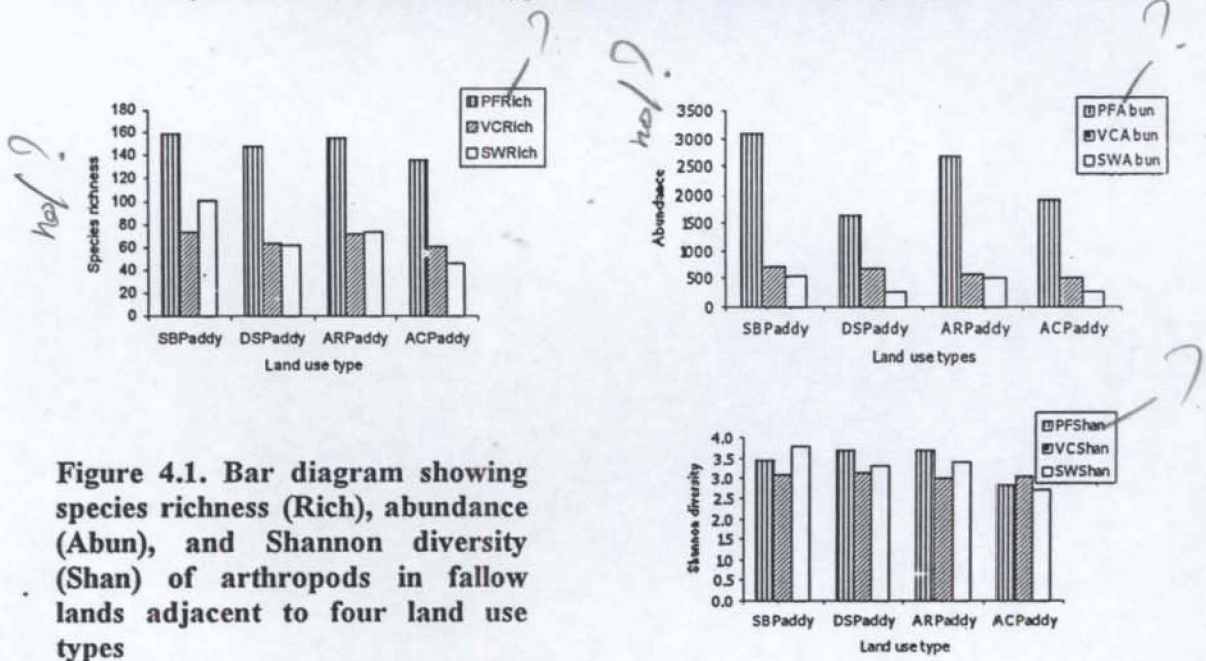


Figure 4.1. Bar diagram showing species richness (Rich), abundance (Abun), and Shannon diversity (Shan) of arthropods in fallow lands adjacent to four land use types

Figure 4.2). The box plot illustrated that the fallows adjacent to each of the four land use types had more ground arthropod diversity, when compared to aerial arthropods (Larger the length of inter quartiles and upper quartiles of box plots, the variation in the data is

more). When data from all sampling methods were pooled, the difference in the median species richness and abundance of arthropods of fallows adjacent to four land use types were highly insignificant: $H(df\ 3, N\ 62) = 0.66, P = 0.88$ (Species richness), and $H(df\ 3, N\ 62) = 0.33, P = 0.95$ (abundance). On floral diversity, the results showed that the difference in the median flora richness of the fallows adjacent to four land use types was highly significant ($H(3, N\ 42) = 11.74, P = 0.008$), but was insignificant for the floral abundance ($H(3, N\ 42) = 0.21, P = 0.97$) (See Table 4.2 and Figure 4.4)

Table 4.2 Statistics of flora of fallows adjacent to four land use types

Land use type	Shannon	Richness	Abundance
SBPaddy	2.36	37	3074
DSPaddy	2.21	32	2501
ARPaddy	2.9	52	3586
ACPaddy	2.03	40	1994

On functional guilds

Ground beetles and spiders were the major predatory arthropods of the fallows during uncultivated season. Kruskal Wallis rank ANOVA showed that the differences in the species richness ($KW\ H(3, N\ 42) = 4.13, P = 0.24$) and abundance ($H(3, N\ 42) = 1.36, P = 0.71$) of ground beetles of the fallows adjacent to four given land use types in question were not significant. The box plot given in the Figure 4.3 illustrated that the fallows adjacent to AR orchards, relative to other landscapes, varied more on Carabid species richness. While, the variation in Carabid abundance in fallows adjacent to AR orchard and AC plantations was relatively less, when compared to other two agro-landscapes. Results also showed that fallows adjacent to Acacia plantations (ACPaddy) were more species rich, and the one close to Areca Orchards (AR) least species rich. Meanwhile, the difference in the median species richness ($H(3, N\ 42) = 4.06, P = 0.25$) and number of individuals ($H(3, N\ 42) = 1.22, P = 0.74$) of spiders of the fallows in four agro-landscapes were not statistically significant. The box plots showed that the fallows adjacent to DS vary more on spider species richness, but were least on abundance data. However, fallows near AC were more or less homogeneous, with minimal variation between study sites, when compared to other agro – landscapes (See Figure 4.5).

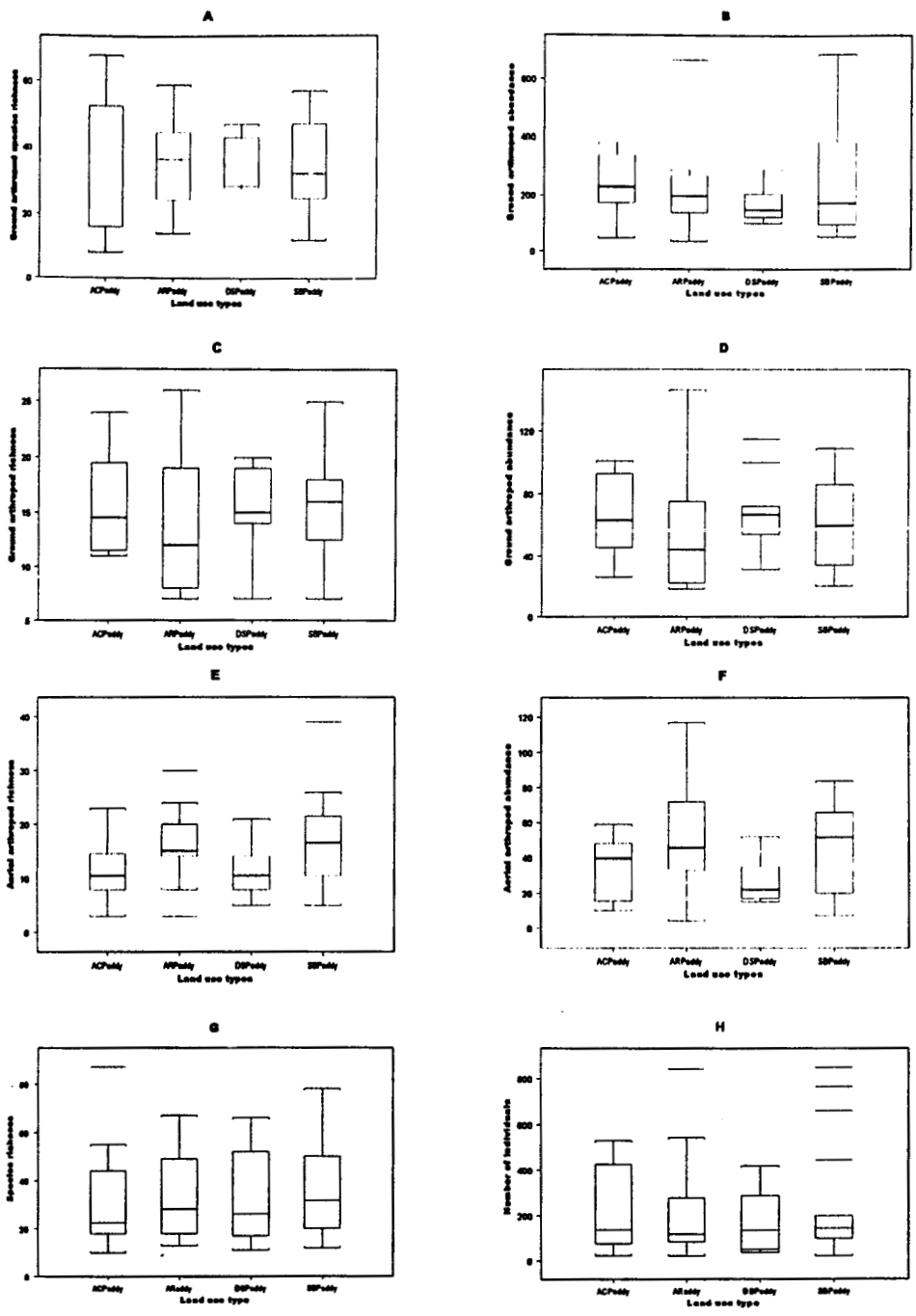


Figure 4.2 Box plot illustrating median species richness and abundance of arthropods of fallows in four agro-landscapes (A-B Pitfall data; C-D All out search data; E-F Sweep data; G-H Whole data pooled)

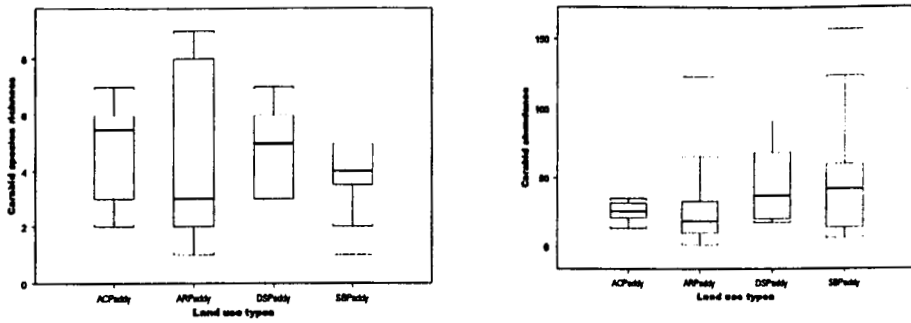


Figure 4.3 Box plot showing median species richness and abundance of Carabid beetles of fallows adjacent to four land use types

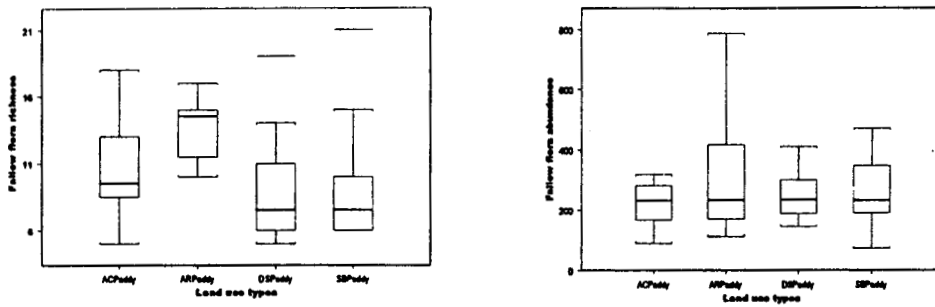


Figure 4.4 Box plot showing median floral species richness and abundance of fallows adjacent to four land use types

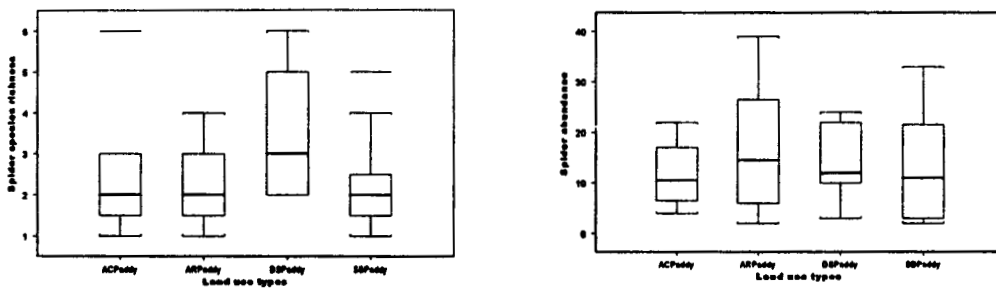


Figure 4.5 Box plot showing median species richness and abundance of spiders in the fallows adjacent to various land use corridors

English!

4.3.1.3 COMPARISON OF ARTHROPOD AND FLORA DIVERSITY OF CROP SEASON PADDY FIELDS ADJACENT TO FOUR LAND USE TYPES

Kruskal Wallis ANOVA was used to compare floral diversity of paddy bunds, aerial arthropods, and selected functional groups like parasitoid and pest population of the cultivated paddy fields in various agro-landscapes.

The results showed that floral diversity of bunds of paddy fields adjacent to four land use corridors were not significantly different (Table 4.3 & Figure 4.6). It was $H(3, N 39) = 3.94, P = 0.26$, and $H(3, N 39) = 2.86, P = 0.41$, respectively for the species richness and abundance of flora of the bunds. A comparison of median and variance of data by box plot showed that flora richness of bunds adjacent to AC plantations varied more between paddy fields. While, the variance in the data on floral abundance was almost uniform across study sites (See Figure 4.6).

Table 4.3 Statistics of flora of paddy bunds in crop season

Land use	Shannon	Richness	Abundance
SBPaddy	3.45	85	5261
DSPaddy	3.49	82	3281
ARPaddy	3.30	78	5000
ACPaddy	3.09	71	3698

The analysis of sweep sampling data showed that both species richness ($H(3, N 41) = 1.07, P = 0.78$), and number of individuals of arthropods ($H(3, N 41) = 2.00, P = 0.57$) were not significantly different between four paddy agro-landscapes. The difference in the species richness ($H(3, N 39) = 2.63, P = 0.45$) and abundance ($H(3, N 39) = 3.5, P = 0.39$) of parasitic wasps between paddy fields adjacent to four land use types also was insignificant (See Figure 4.6)

When data from malaise ^{traps} sampling was considered, species richness of aerial arthropods of paddy fields adjacent to four land use types were significantly different, $H(3, N 19) = 7.72, P = 0.05$, but the difference in the number of individuals of arthropods between paddy fields of four landscapes was not significant $H(3, N 19) = 3.66, P = 0.30$. However, on sweep + Malaise pooled data, both species richness ($H(3, N 21) = 3.44, P = 0.33$) and abundance ($H(3, N 21) = 1.84, P = 0.60$) of arthropods were insignificant between paddy fields.

not significantly different

From the box plots (Figure 4.6) it is understood that variance in aerial arthropod richness ^{was} were relatively more in the paddy fields adjacent to AR orchard. But, paddy fields adjacent to DS showed more variance in the abundance data, when compared to other agro-landscapes. However, the data on parasitic wasps showed that paddy fields adjacent to AR orchards to vary more between study sites in species richness, while paddy fields near to AR orchards and DS were equally diverse in parasitic wasps' abundance. The results demonstrate that, although extremes in the diversity of aerial arthropod as well as parasitic wasps occur in paddy fields, when average values of the diversity measures are taken, the difference in the diversity of arthropods across study sites is minimal or almost nil.

On the other hand, the ANOVA results on a locally major pest, *C. medinalis*, of cultivated paddy fields showed that the difference in the pest population density in paddy fields of four paddy agro landscapes were significantly different ($H(3, N 124) = 12.40, P = 0.006$). However, no considerable difference in variance in population density and infestation of *C. medinalis* was observed in any of these agro-landscapes, except some extreme cases (See Figure 4.7). Meanwhile, the difference in number of the pest-infested saplings of the cultivated paddy fields in four agro-landscapes was highly significant ($H(3, N 124) = 20.07, P = 0.0002$). The box plots demonstrated a large variation in the infestation rate in the paddy fields adjacent to AC plantations, relative to other paddy agro-landscapes. From the box plots (Figure 4.7) it is also understood that population density of this particular pest as well as infestation rate was relatively more in the paddy fields adjacent to simplified agro-landscapes, and was least in the *Soppinabetta* related paddy fields.

What is agro-landscapes?

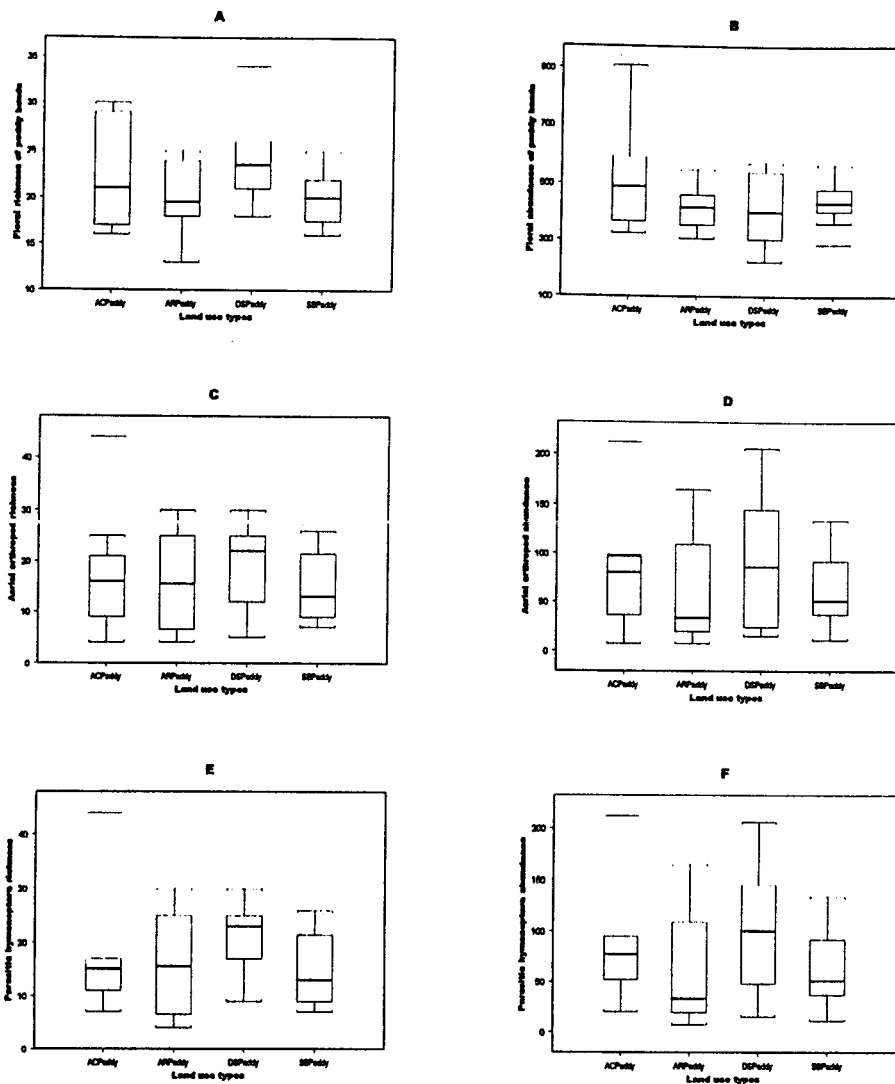


Figure 4.6 Box plot showing median species richness and abundance of wild flora of paddy bunds (A&B), aerial arthropods (C&D), and parasitic wasps (E&F) in four agro-landscapes during crop season

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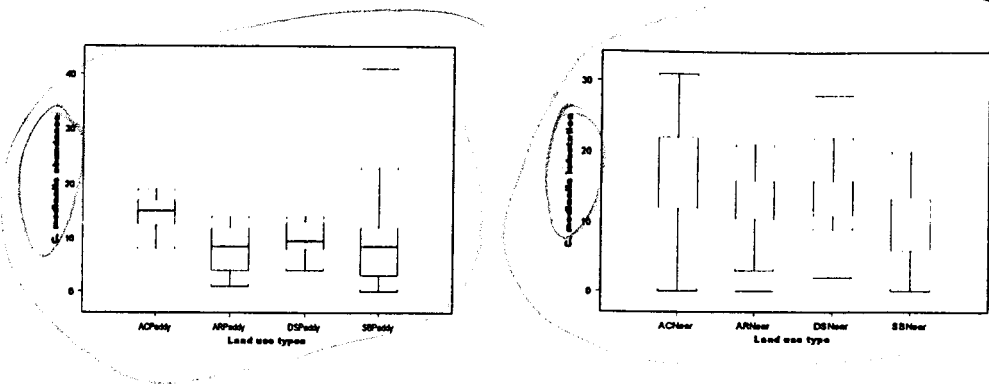


Figure 4.7 Box plot showing median *C. medinalis* population density and infestation in the paddy fields adjacent to four land use types

4.3.1.4 IMPACT OF ADJACENT LAND USE TYPES ON RICE GRAIN PRODUCTION IN RICE PADDY AGRO-ECOSYSTEMS

Kruskal Wallis rank ANOVA results showed that both rice grain count ($H (df 3, N 270) = 57.91, P = 0.0000$) and fresh grain weight ($H (df 3, N 225) = 16.75, P = 0.0008$) were highly significantly different between rice paddy agro – ecosystems adjacent to four land use types. However, no considerable difference in the *Leptocorisa* infested grains ($H (df 3 N 270) = 2.52, P = 0.47$) was found between rice paddy lands adjacent to four land use types. (See Figure 4.8 for details).

One cannot read the graphs

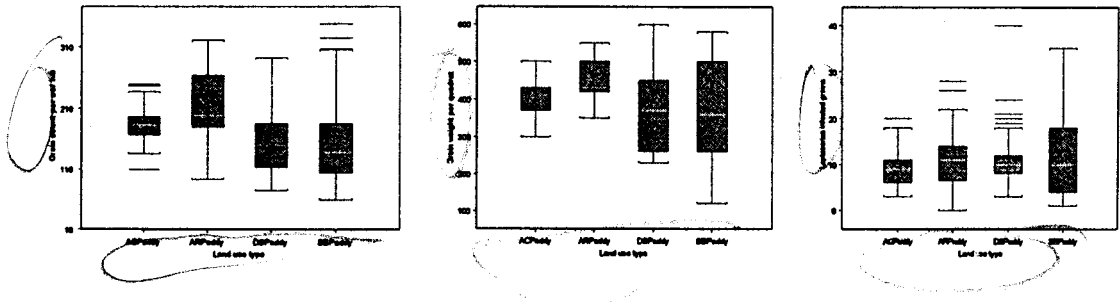


Figure 4.8 Box plot showing difference in median grain count, weight and *Leptocorisa* infested grains in paddy fields adjacent to four land use types

4.3.2 COMPARISON OF ARTHROPOD COMMUNITY AND RICE GRAIN PRODUCTIVITY IN A DISTANCE GRADIENT FROM PADDY – LAND USE INTERFACE TOWARDS CENTER

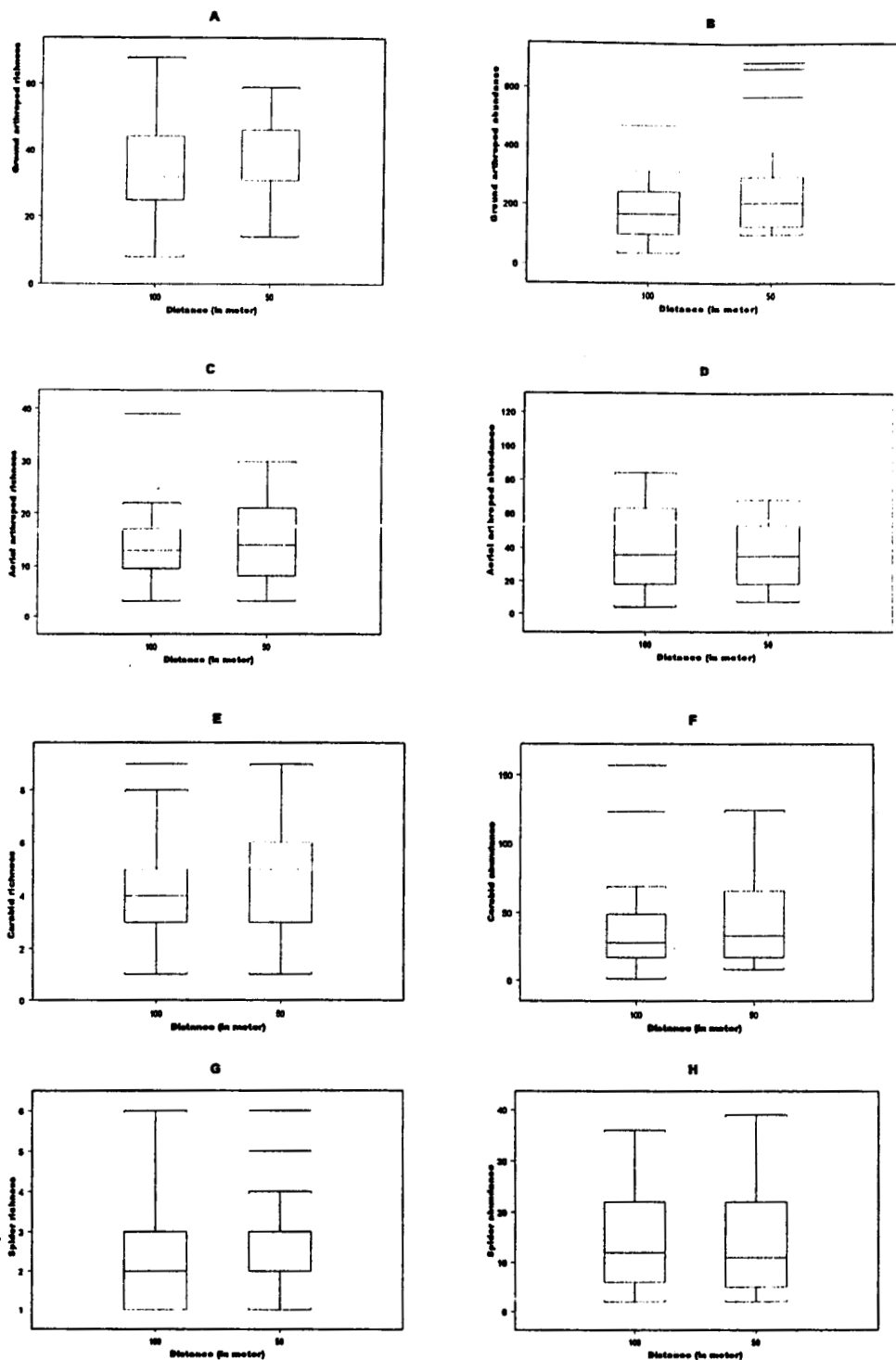
4.3.2.1 Arthropod community of fallow *land*

The study hypothesized that the impact of distance gradient on insect community assemblages would be negative, and predicted that when one moves from corridor edges to the interior of the paddy fields, diversity of the insects would be reduced. The hypothesis was proved correct, where in most cases the diversity of the arthropods was decreasing, when moving away from the edge to the center of fallow lands. However, Mann Whitney U test has shown that the distance from the paddy – land use interface, did not significantly affect species richness (Mann Whitney U test, $N = 21$, $P = 0.35$) and number of individuals (U test, $N = 21$, $P = 0.35$) of ground arthropods collected on pitfalls. But, average or median of both the diversity measures were more in the subplot close to paddy edge, i.e. PA50 (See Figure 4.9), when compared to the one located 100 m away from the edge. The results were almost same for the major functional guilds of fallow lands too. The difference in carabid species richness (U test, $N = 21$, $P = 0.23$), abundance (U test, $N = 21$, $P = 0.53$), and ground dwelling spider species richness (U test, $N = 21$, $P = 0.43$) and abundance (U test, $N = 21$, $P = 0.92$) were highly insignificant between two distance levels of fallows (See Table 4.4. and Figure 4.9).

Table 4.4. Mann Whitney U test results for fallow land arthropods

	Sum rank			Z	p-level	Valid N	
	PA 100	PA 50	U			PA 100	PA 50
Aerial Arthro. Abundance	419	401	191	0.24	0.81	20	20
Aerial Arthro. Richness	397	423	187	-0.35	0.73	20	20
Ground Arthro. Abundance	391.5	511.5	160.5	-1.51	0.13	21	21
Ground Arthro. Richness	414	489	183	-0.94	0.35	21	21
Carabid Abundance	427	476	196	-0.62	0.54	21	21
Carabid Richness	405	498	174	-1.17	0.24	21	21
Spider Abundance	448	455	217	-0.09	0.93	21	21
Spider Richness	424	479	193	-0.69	0.49	21	21

What is Arthro.



*one cannot
read this
figure*

Figure 4.9 Box plot showing median species richness and abundance of ground (A&B), and aerial arthropods (C&D), Carabid beetles (E&F), and ground spiders (G&H) in a distance gradient (PA 50 and 100) in fallows.

4.3.2.2 Arthropod community of crop season paddy fields

In contrast to the arthropod community of fallow lands, diversity and density of aerial arthropods, particularly parasitoids and *C. medinalis* were increasing with distance from the crop season paddy edges. However, this increase is not significantly different either in the aerial arthropod ($Z = 1.23$, $P = 0.22$; $Z = 0.09$, $P = 0.93$ for richness and abundance respectively), or parasitoid ($Z = 1.05$, $P = 0.29$; $Z = 0.31$, $P = 0.76$ respectively for richness and abundance) diversity as distance from land use edge increased, and it was the same case for the pest, *C. medinalis* density ($Z = -0.76$, $P = 0.45$) and infestation ($Z = -0.09$, $P = 0.93$). (See Table 4.5 and Figure 4.10 for more details).

Table 4.5 Mann Whitney U test results for crop season paddy arthropods

	Sum rank			Z	p-level	Valid N	
	PA 100	PA 50	U			PA 100	PA 50
Arthropod abundance	423.5	437.5	206.5	0.09	0.93	20	21
Arthropod richness	467	394	163	1.23	0.22	20	21
Parasitoid abundance	391	389	179	0.31	0.76	19	20
Parasitoid richness	417.5	362.5	152.5	1.05	0.29	19	20

Kruskal Wallis rank ANOVA showed that difference in density ($H(df 2, N 124) = 2.14$, $P = 0.34$) and infestation rate ($H(df 2, N 124) = 2.78$, $P = 0.24$) of *C. medinalis* in a distance gradient was not significant.

4.3.2.3. Comparison of rice grain productivity in a distance gradient in rice paddy agro-ecosystems

Results showed no considerable difference in the median count of grains ($H(df 2, N 270) = 0.22$, $P = 0.89$) and *Leptocorisa* infestation ($H(df 2, N = 270) = 0.85$, $P = 0.65$) with distance away from the edge of rice paddy fields. However, a considerable increase in the total weight of grains was found with distance away from the edge ($H(df 2, N 225) = 9.31$, $P = 0.0095$). See Figure 4.11 for more statistics.

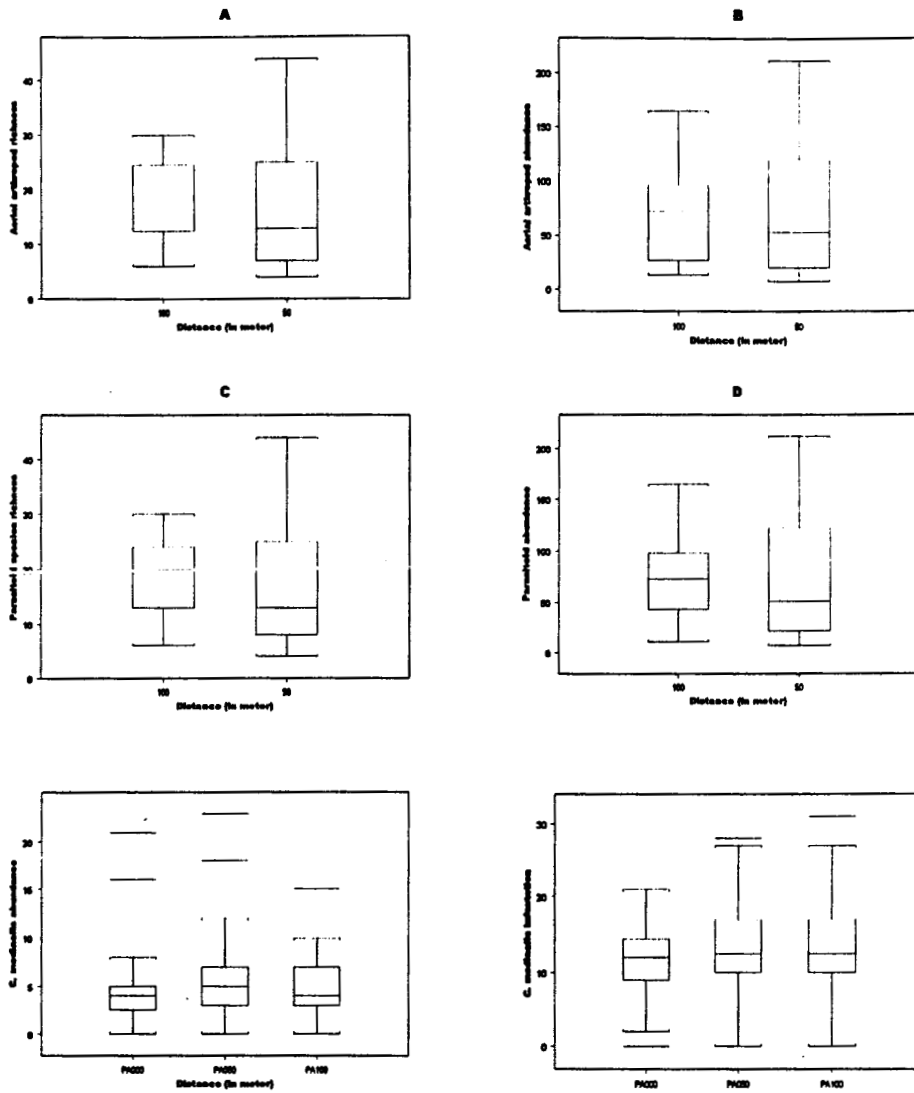


Figure 4.10 Box plot showing median species richness and abundance of aerial arthropods (A&B), parasitoids (C&D), and *C.medinalis* population and infestation (E&F) in a distance gradient (PA 0, 50 and 100) in crop season paddy fields.

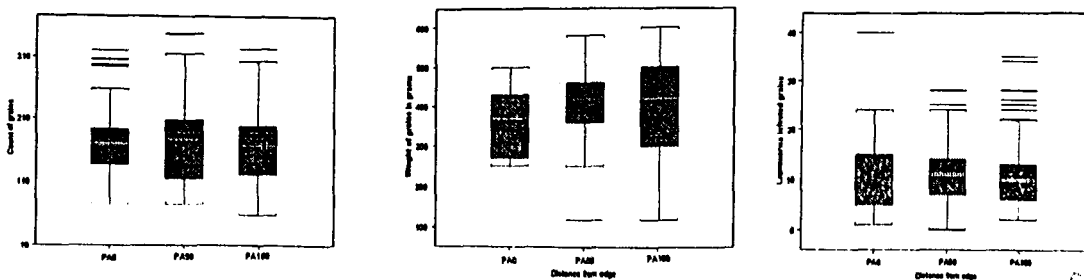


Figure 4.11 Box plot showing median count and weight of grains and *Leptocorisa* infestation in a distance gradient in the rice paddy agro-ecosystems

4.3.3 COMMUNITY COMPOSITIONAL SIMILARITY OF ARTHROPODS AND WILD FLORA BETWEEN PADDY FIELDS AND ADJACENT TREE BASED LAND USE TYPES

This is one of the major objectives of this study. It is assumed that by studying the proportion of the shared species between paddy fields and adjacent land use types, we would be able to answer the movement and dispersal capability of arthropods in crop season and fallow period. A study was also conducted to compare the off-season fallows and crop season paddy fields by looking into the magnitude of the species turn over between seasons. Jaccard's similarity index using group average linkage was used to visually interpret the proportion of the shared arthropod species between paddy fields and other land use types, and among paddy fields across study sites.

The results have shown that a good proportion of species turn over occurs in the arthropod community of paddy fields across season (please see Appendix I for the details of species shared between various land use types and paddy fields in fallow and crop seasons). The dendrogram (Figure 4.12) shows that rice paddy agro – landscapes of two seasons were highly dissimilar in aerial arthropods, and only 11 % of arthropods were found in rice paddy agro – landscape during both seasons. Treatments of each season clustered on each arm of the cluster tree. The tree diagram also showed that aerial arthropod species between paddy fields are more similar in crop and fallow seasons, rather than paddy fields and adjacent land use types. The similarity in aerial arthropods was observed more in the crop season, when compared to the off-season. More than 40 % of the arthropods were common to all the paddy fields, irrespective of the adjacent land

NB5642

use types. Paddy fields showed more similarity in aerial arthropod fauna in the crop season, with Areca Orchards (ARCrop) than with any other adjacent corridor habitat. A good proportion of Dipterans (mainly Dolichopodids and Chironomids) and parasitic hymenopterans (particularly Scelionids and Mymarids) were found in both the paddy fields and AR orchard in the crop season (See Appendix I). Meanwhile, in the off-season, fallow lands had shown more affinity to the Acacia plantations (ACOff), rather than any other tree based adjacent land use types.

Jaccard Cluster Analysis (Group Average Link)

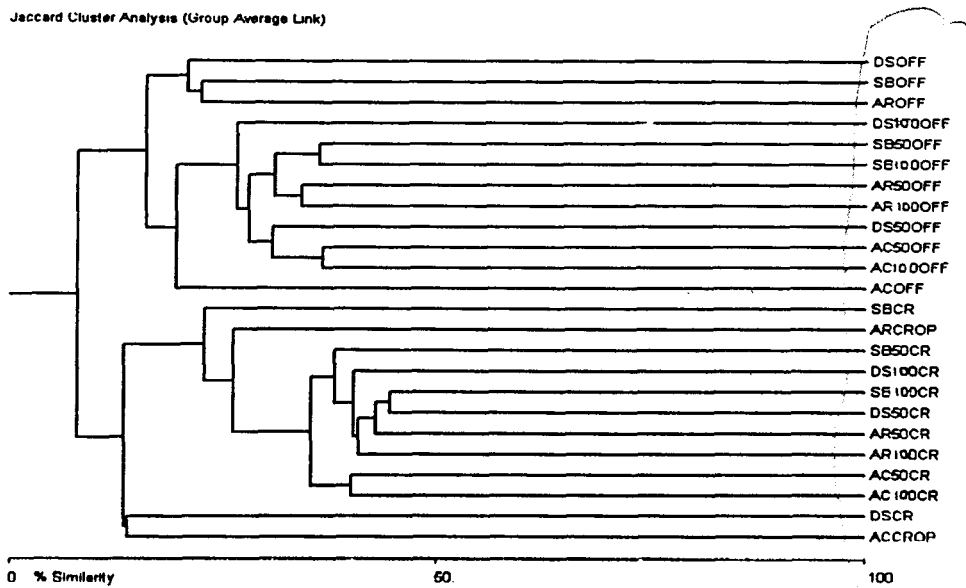


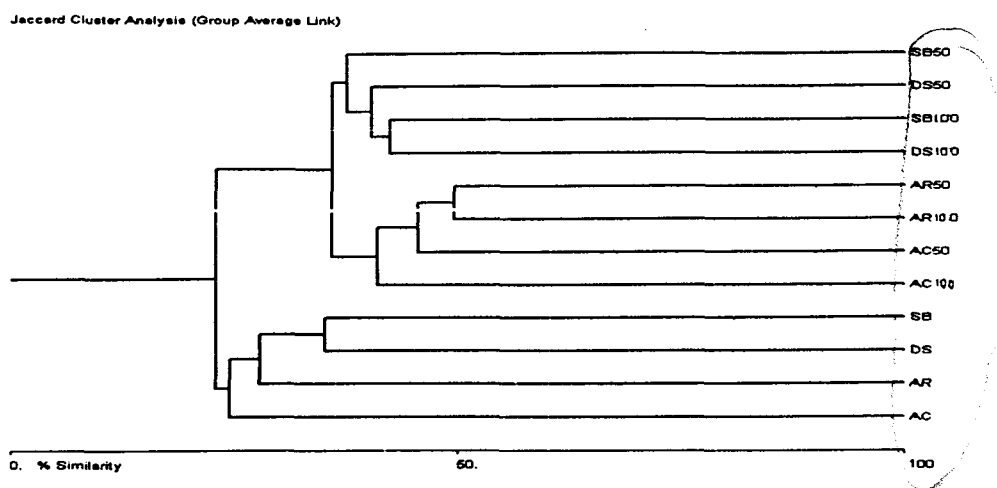
Figure 4.12 Dendrogram showing percentage of similarity of treatments on aerial arthropod community of rice paddy agro – landscapes in two seasons.

The results showed a seasonal variation in arthropod assemblages, particularly on aerial arthropod, in rice paddy agro-landscapes of Sringeri. The study also concludes that the aerial arthropod assemblages of paddy fields at a regional level would be more similar than ground arthropods.

4.3.3.2 Similarity of arthropod community between fallows and adjacent land use types

The dendrogram constructed on pitfall ^{trap collected} data (Figure 4.13) showed that ground based arthropod community in fallow lands and tree based adjacent land use types were entirely different. However, nearly 22 % of ground arthropods were shared between the fallow lands and adjacent uncultivated land use types. The cluster diagram also showed that

diversified habitats like Degraded Scrub (DS) and *Soppinabetta* forests (SB) to be more similar on ground arthropod community, than the simplified habitats like AC and AR. The pair wise Jaccard's similarity matrix also showed that fallows adjacent to diversified habitats (SB and DS) to be more similar on ground arthropods, and was different from the fallows adjacent to monoculture plantations; less than 35 % of the ground arthropods were found shared between these two sub clusters.



Handwritten note: *low similarity*

Figure 4.13 Dendrogram showing similarity between fallows and adjacent land use types on ground arthropods

Dendrogram on aerial arthropods (Figure 4.14) collected by sweeping, had given a similar result as the ground arthropods for the fallow period, however, with a slight change in the clustering pattern. Tree based land use types clustered on one branch and the fallows clustered on the other. However, the percent of similarity between these two major clusters was only 11% for the aerial arthropod community. Unlike ground arthropod based cluster diagram, AR orchard has shown more affinity to DS forest when active fliers are considered. But, in the fallows, the paired AR adjacent fallows had shown more similarity to the SB adjacent fallow lands, nearly 34 % of the aerial arthropods were shared by the fallows adjacent to these landscapes.

Handwritten note: *~ 34% similarity*

The dendrogram constructed on Malaise traps (Figure 4.14) was unique by its appearance. Unlike, the pitfall and sweep methods, actively flying insects showed relatively more affinity towards the fallow lands adjacent to land use types especially AC,

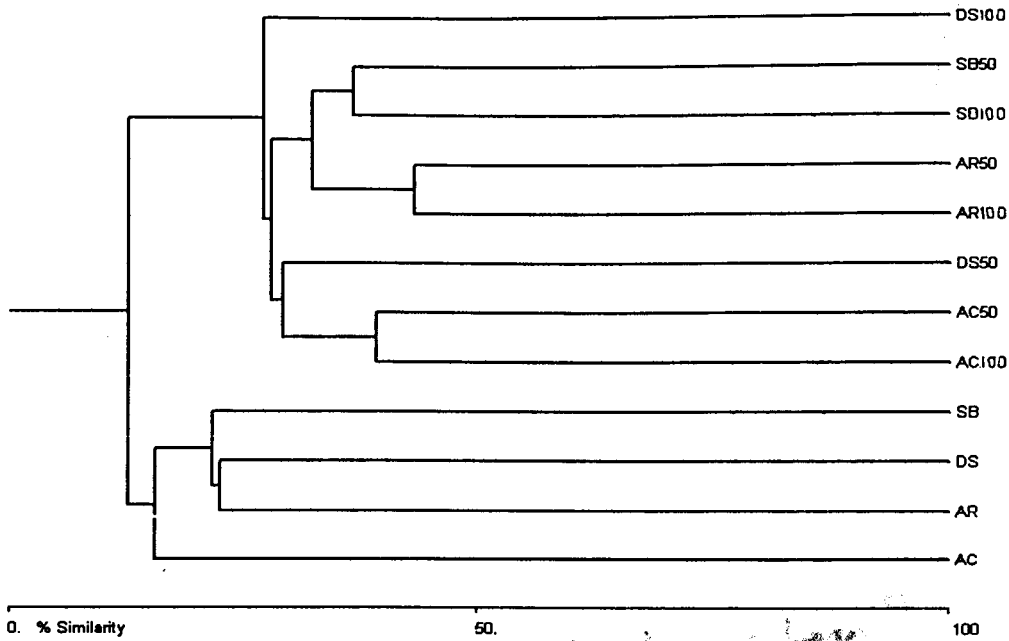
AR and SB, which is primarily attributable to the vagrant flying insects (See Figure 4.14).

4.3.3.3 *Similarity of functional arthropod community between paddy fields and adjacent land use types*

Pair-wise cluster analysis based on Jaccard's similarity index was used to study the similarity of arthropod functional groups like predators, parasitoids and pests between paddy fields and adjacent uncultivated land use practices. Spiders and ground beetles (Carabidae: Coleoptera) were identified as the major predatory groups of the fallow lands in the uncultivated season. However, parasitic ~~hymenoptera~~ was the major beneficial functional group in the crop season rice paddy fields.

For the pooled Off and Crop season data, three major functional groups, generalist predators, parasitic groups, and pests, were used for the analysis. Based on field observations and available secondary literature, specific members of each family were assigned to each of these functional groups. However, only Sweep and Malaise data were used for this cluster analysis. Generalist predatory group comprises of beetles, Carabidae, Staphylinidae, Anthicidae, Coccinellidae, and Cicindelidae, the entire Aranaeae (Spiders), flies of families Asilidae, Dolichopodidae, Empididae, Tabanidae, Ephydriidae (in part), Pipunculidae, and Phoridae, bugs like Reduviids, hymenopteran families - Chrysididae, Dryinidae, Sphecidae, Vespidae, Pompilidae, Scoliidae, Mutillidae, and Tiphidae. Parasitic group includes the whole parasitic hymenopterans, and Tachinid, and Sarcophagid flies. The pests included in the analysis were the beetles of various families (Cantharidae, Chrysomelidae, Curculionidae, Meloidae, Melyridae, and Phalacridae), bugs (Pentatomidae, Coreidae), Homopterans (Cicadellidae, Cixiidae, Delphacidae, Flatidae, Issidae), the entire Lepidopterans (mainly *Cnaphalocrocis medinalis*, *Melanitis leda ismene*, *Nymphula depunctalis*, *Parnara mathias*, *Spodoptera spp.* *Euproctis sp.*) and thrips (Phlaeothripidae).

Jaccard Cluster Analysis (Group Average Link)



Jaccard Cluster Analysis (Group Average Link)

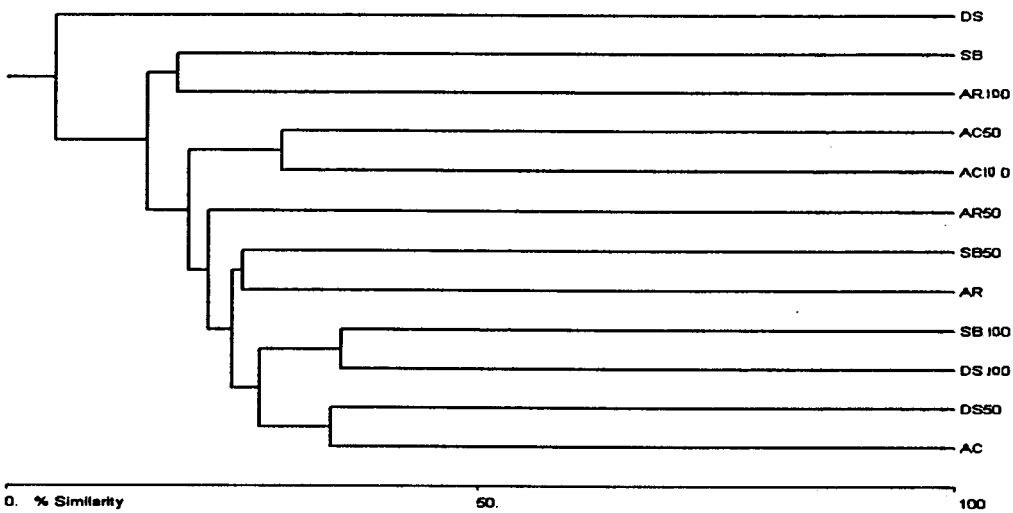


Figure 4.14 Dendrograms illustrating the aerial arthropod community compositional similarity between fallows and other tree based land use types (sweep and Malaise data)

4.3.3.3.1 Similarity of predatory Carabid beetles and Spiders between fallows and adjacent land use types

The dendrogram based on species' composition illustrated that tree based land use types were considerably different from the fallows in ground beetle assemblages, and branched out as a separate cluster from the fallow land group (Figure 4.15). However, similar to dendrogram on the entire ground arthropods (Figure 4.12), the natural tree based land use types, such as SB and DS showed more ground beetle compositional similarity, and ground beetles of monoculture plantations (AC and AR) were also similar to each other. The impact of the adjacent land use types was relatively less on the fallow specific Carabid beetles, and showed that fallow specialists were an entirely different entity from the land use types.

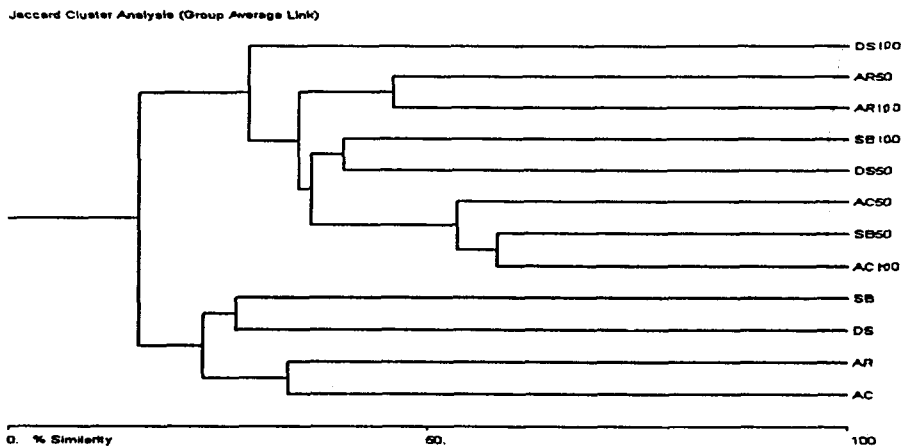


Figure 4.15 Cluster analysis dendrogram illustrating similarity between paddy fields adjacent to various corridor types, and corridors in ground beetle community composition in off-season

The ground beetle community collected by pitfall alone also had shown a similar pattern as observed for the entire Carabid data, however, with a slight change in percent of similarity between pairs. But the cluster analysis again brought out two major clusters; fallow lands alone and adjacent land use types alone at two of its branches, with a similarity of 23 % between these two clusters, which was almost similar for the pooled data.

The tree diagram on ground dwelling spider community illustrated (Figure 4.16) that although it was not considerably high, the percent of compositional similarity of spiders

between fallows and other adjacent land use types were relatively high, than that for any other taxa or functional groups. Although dendrograms at three levels, on whole data, on each method separate, and PF + All out search data alone, were constructed on spider community composition, as all the cluster diagrams had shown similar kind of linkage, the dendrogram on PF + All out search spider data alone is illustrated here. The data of 35 species belonging to 10 spider families alone were used in the analysis. Data of four families, Araneidae, Oxyopidae, Linyphidae, and Theridiidae, which were collected using Sweeping and Malaise traps, were not used in the present analysis.

The dendrogram has given two major clusters, one with AC plantation and the corresponding fallow land (AC100), which had shown > 30 percent similarity with the other large cluster of fallows and other tree based land use types. The results drew an interesting conclusion that more species of ground dwelling spiders were observed both in fallow lands and other adjacent land use types during off-season than any other taxa. The results can also be interpreted in such a way that the ground living spiders would be the only taxa having a good dispersal capacity, which enable them to move between paddy fields and adjacent land use corridors.

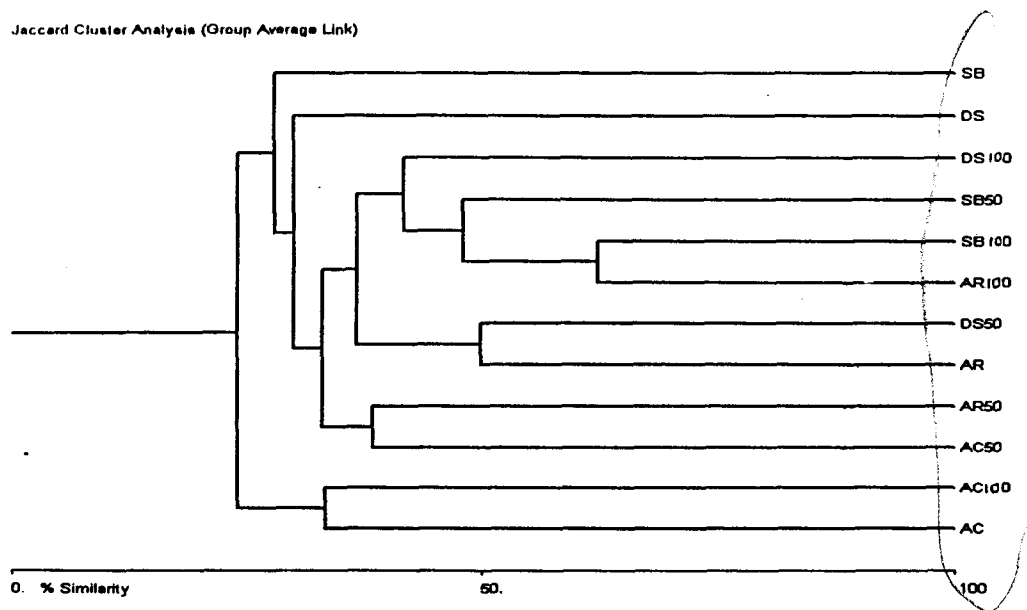


Figure 4.16 Cluster analysis dendrogram illustrating similarity between paddy fields and other land use types on ground dwelling spider community

4.3.3.3.2 Similarity of parasitic hymenopterans (PH) between fallows and adjacent land use types

The major functional group studied in the crop season was parasitoids, which mainly comprised of parasitic hymenopterans. The dendrogram on PH community has given almost similar linkage pattern as the entire crop season data. The pair-wise cluster analysis brought out two major clusters, one branch with DS – AC land use types, as like the entire crop season data (see Figure 4.12 for crop+off season data), and the other with rest of the treatments. The dendrogram (Figure 4.17) again has illustrated that paddy fields with AR orchards as the adjacent land use type had the highest parasitic

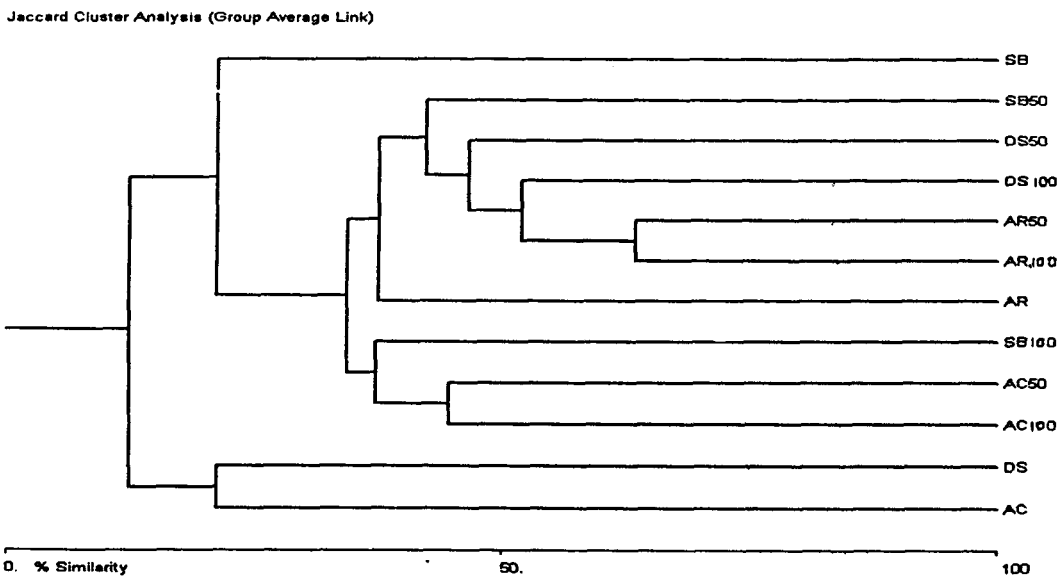


Figure 4.17 Cluster analysis dendrogram illustrating similarity between paddy fields and adjacent land use types on parasitic hymenopteran (PH) community composition in crop season

hymenopteran species composition. However, the similarity between SB and paddy fields on PH species composition was relatively low (nearly 20 %). The analysis also demonstrated that the species composition of paddy fields adjacent to each of the land use types happens to be more similar than the paddy fields across land use types.

4.3.3.3.3 Similarity of predatory, parasitoid and arthropod pest community between paddy fields and adjacent land use types

The major functional groups used to study the cluster analysis were general predatory arthropods, parasitic insects, and insect pest populations. The species and the families

used for the analysis are described at the beginning of this session. Meanwhile, the data generated on Malaise and Sweep samples alone was used for the analysis, as those were the only two sampling methods carried out both in off-season and crop season.

The dendrogram (Figure 4.18) on the predatory arthropod community composition brought out two major clusters: one cluster represented by two land use types during crop season, AC and DS, and the other cluster with all other treatments. The similarity of AC and DS on predatory arthropod community composition here resembles the cluster diagrams on parasitic hymenopterans and the entire crop season data (see Figures 4.18 & 4.13). In the other cluster, two sub-clusters, one exclusively for crop season, and the other only for the off-season, showed that 15 percent of aerial predatory arthropods were common in Sringeri rice paddy agro – landscapes during the two seasons. The results also revealed that predatory arthropod community of the paddy fields are more or less similar at a regional level, and the influence of nearby land use type at least for this functional guild is almost absent.

The pair-wise cluster analysis on parasitic insects illustrated a dendrogram (Figure 4.19), which is similar to the one for the predatory arthropods, but with slight changes in the linkage pattern. Here DS of off-season came out from the other large cluster of paddy- fields and other land use corridor habitats of both the seasons. The linkage pattern of treatments in this large cluster, which comprises of off-season and crop season treatments, has given almost a similar kind of tree diagram as that for predatory arthropod community; parasitic arthropods were more similar in corridor habitats and paddy fields during both the seasons, when compared to predatory arthropods.

On pest community, the pair-wise similarity study formed two major clusters, one with off-season treatments, and the second branch exclusively for crop season treatments (Figure 4.20). Only less than 10 percent of similarity was observed between these two major clusters. The percent of similarity between paddy fields was more than 50 percent on crop season data, and the pest population of paddy fields close to natural tree based corridors (SB and DS) was more similar.

Jaccard Cluster Analysis (Group Average Link)

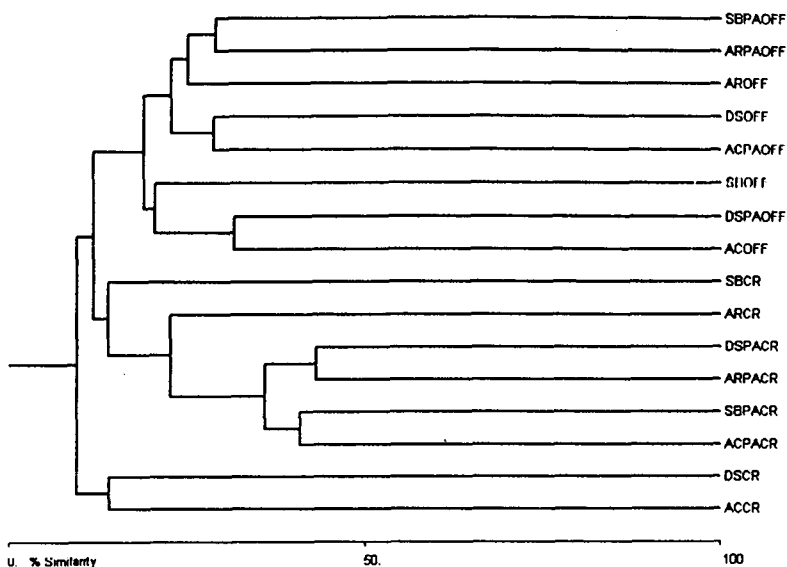


Figure 4.18 Dendrogram illustrating similarity in generalist predatory arthropods between paddy fields and other land use types of crop and off-season on pooled sweep and Malaise data

Jaccard Cluster Analysis (Group Average Link)

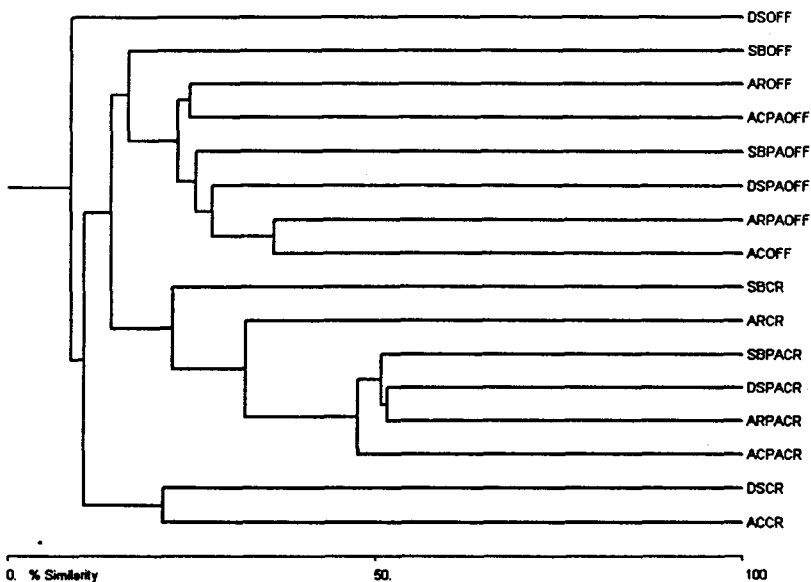


Figure 4.19 Dendrogram illustrating similarity in generalist parasitoid arthropods between paddy fields and other land use types of crop and off-season on pooled sweep and Malaise data

Jaccard Cluster Analysis (Group Average Link)

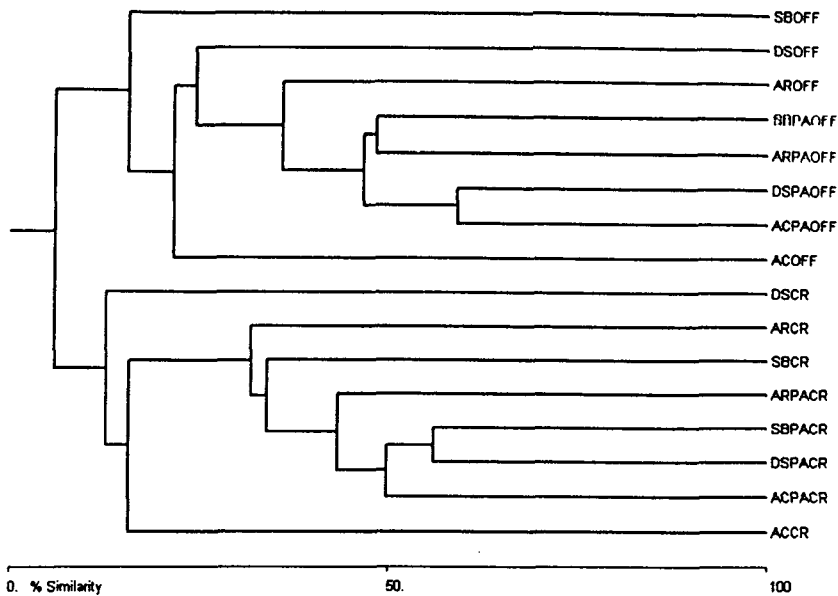


Figure 4.20 Dendrogram illustrating similarity in pest community between paddy fields and corridor types of crop and off-season, on pooled sweep and Malaise data

The results conclude that the pest population of the crop season rice paddy agro - ecosystems is entirely different, from the one seen in the off-season fallow period. The similarity observed between crop and off-season clusters were due to some minor pests, such as two unidentified species of thrips (Phlaeothripidae), and apparent pests like some homopterans, coleopterans, and one species of Chironomid fly, which were found to occur in both the seasons, either in paddy field or in corridors. However, major pests like lepidopterans, two major hopper pests such as *Nephotettix virescens* and *Deltocephalus (Recilia) dorsalis*, and other Chironomid flies were abundant only in the crop season and occurrence of these species in off-season treatments was almost nil.

4.3.4 TO ESTIMATE IMPORTANT PARAMETERS APART FROM ADJACENT LAND USE TYPES IN DETERMINING THE ARTHROPOD COMMUNITY STRUCTURE OF SRINGERI RICE PADDY AGRO - ECOSYSTEMS

This is the other important objective of the study, to ascertain the important parameters, apart from the adjacent land use type in determining the arthropod community structure of fallow or paddy land in off and crop seasons.

Spearman rank order correlation and Regression techniques were used to estimate the statistical significance of microclimatic and vegetational parameters. Stepwise multiple regression analysis was used to identify the best combination of variables as predictors of vegetation and arthropod diversity in paddy fields. The *coefficient of determination* (r^2) suggests the proportion of the variability in the y observations that can be accounted for by variability in the x observations. One-way ANOVA was used to test the significance of the slope of the line, in regression. Significance in the Beta values was compared by t test.

Regression analysis was conducted broadly at two levels: on microclimatic variables, and vegetational variables of fallows, adjacent land use types, and bunds.

4.3.4.1 CORRELATION BETWEEN INDEPENDENT AND ARTHROPOD VARIABLES

4.3.4.1.1 Paddy field variables as independent variables

Average soil P_2O_5 (Kg./Ac), pH of soil, percent Organic Carbon (% OC), Average soil temperature, Average soil Humidity were used as the independent soil variables. As a first step in the analysis, correlation between these microclimatic variables were estimated and are given in the Table 4.6. The significant correlations are highlighted by bold figures (P to enter < 0.05). The correlogram showed that except for a significant negative relationship between soil pH and Percent of Organic Carbon content of soil ($t_{40} = - 2.53, P = 0.01$), and soil temperature and humidity ($t_{30} = - 2.12, P = 0.04$), no other significant correlations were observed among these independent variables.

Table 4.6 Spearman rank order correlation between microclimatic variables of fallow lands.

	PH	OC %	AV P_2O_5	AV Soil Tem	AV Soil Hum
Paddy Soil pH	1				
Organic Carbon (OC %)	-0.372	1			
Av. P_2O_5	0.081	0.269	1		
Av. Soil Temperature	-0.079	0.079	-0.006	1	
Av. Soil Humidity	-0.045	0.09	-0.216	-0.362	1

Vegetation attributes like richness and abundances of fallows were selected as the dependant variables. The Spearman rank correlation has shown that both vegetation stand density ($t_{32} = 5.60, P = 0.00003$) and richness ($t_{32} = 3.91, P = 0.0004$) were

significantly positively correlated to the soil humidity. Meanwhile, a significant negative correlation between Av. soil P₂O₅ content and vegetation stand density ($t_{40} = -2.09$, $P = 0.04$) of the fallows was observed (Table 4.7).

Correlation studies were also conducted to assess the statistical significance of microclimatic and vegetational parameters on ground arthropod diversity of fallows. Species richness and abundance were considered as the measures of arthropod diversity. Ground arthropod richness of the fallows was significantly positively correlated to soil humidity ($t_{32} = 2.03$, $P = 0.04$), vegetational stand density ($t_{40} = 2.07$, $P = 0.04$), and percentage of grass cover ($t = 2.31$, $P = 0.02$). But, a weak correlation between ground arthropod richness and vegetation stand richness was observed, and was not significant ($t_{30} = 1.92$, $P = 0.06$). Meanwhile, no significant correlations were observed between ground arthropod abundance and any of the microclimatic or vegetational variables (Table 4.8).

Table 4.7 Spearman rank order correlation between soil variables and paddy field vegetation attributes of fallows.

	VegAbundance (stand density) of fallows	Veg Richness (stand richness) of fallows
Paddy Soil pH	-0.038	-0.008
Organic Carbon (OC %)	0.175	0.218
Av. P ₂ O ₅	-0.315	0.126
Av. Soil Temperature	-0.115	-0.096
Av. Soil Humidity	0.704	0.569

Table 4.8 Spearman rank order correlation between paddy field variables and ground arthropod abundance and richness of fallows.

	Ground arthropod abundance of fallows	Ground arthropod richness of fallows
Paddy Soil pH	-0.011	-0.183
Organic Carbon (OC %)	-0.166	0.028
Av. P ₂ O ₅	-0.116	-0.116
Av. Soil Temperature	-0.011	-0.168
Av. Soil Humidity	0.04	0.339
% grass cover in paddy field	0.207	0.354
Stand density in paddy	0.064	0.344
Stand richness in paddy	0.258	0.291

Table 4.9 Spearman rank order correlation between fallow variables and aerial arthropod abundance and richness (on sweep data) in uncultivated season.

	Aerial arthropod abundance of fallows (Sweep)	Aerial arthropod richness of fallows (Sweep)
Stand density in paddy	0.467	0.538
Stand richness in paddy	0.355	0.458
Av. Soil Humidity	0.437	0.5
Av. Soil Temperature	-0.12	-0.245
% grass cover in paddy field	0.224	0.368

Spearman rank order correlation between aerial arthropods and microclimatic variables of paddy fields has shown that the total arthropod richness on sweep samples were significantly positively correlated to all of the concerned attributes (stand density, $t_{38} = 3.93$, $P = 0.0003$; Stand richness, $t_{38} = 3.17$, $P = 0.002$; Soil humidity, $t_{32} = 3.26$, $P = 0.002$; % grass cover, $t_{28} = 2.09$, $P = 0.04$), except soil temperature (Table 4.9). Results have shown that paddy field vegetation density was an important parameter for the occurrence of aerial arthropods of fallows. However, the abundance of aerial arthropods of the fallows was significantly positively correlated to the stand density ($t_{38} = 3.25$, $P = 0.002$), vegetation richness ($t_{38} = 2.34$, $P = 0.02$), and soil humidity of the paddy fields ($t_{32} = 2.74$, $P = 0.009$). While, the percent grass cover of the off-season paddy field was not found as a significant correlate to the abundance of aerial arthropods of paddy field (Table 4.9). Both total arthropod species richness and abundance were negatively correlated to the soil temperature in paddy field.

Correlation studies also were carried out to look into the influence of floral diversity of fallows on important functional groups like predatory Carabid beetles and ground spiders in the off-season. Total Carabid beetle abundance and richness were negatively correlated to all of the vegetation attributes, and the inverse correlation was particularly significant between Carabid abundance and other vegetation variables, such as floral abundance, $t_{40} = -3.1$, $P = 0.003$; Floral richness, $t_{40} = -4.3$, $P = 0.0001$; and % of grass cover, $t_{30} = -1.8$, $P = 0.08$. Whereas, the positive correlation between the floral diversity and spider diversity in the fallows (% grass cover vs. spider abundance $t_{30} = 2.46$, $P = 0.01$; % grass cover vs. spider richness, $t_{30} = 2.11$, $P = 0.04$; floral abundance vs. spider abundance, $t_{40} = 3.62$, $P = 0.0007$; floral richness vs. spider abundance, $t_{40} = 2.62$, $P = 0.01$) illustrates the difference in the microclimatic requirements of these two

major predatory groups of paddy fields (Table 4.10). The number of spiders, in contrast to Carabid numbers, increased with the floral abundance in rice paddy fields.

Table 4.10 Spearman rank correlation between vegetation attributes and predatory Carabid beetle and spider community of fallows.

	%Grass cover	Floral Abundance	Floral Richness
Carabid abundance	-0.311	-0.44	-0.565
Carabid richness	-0.156	-0.188	-0.008
Ground spider abundance	0.411	0.503	0.383
Ground spider richness	0.36	0.288	0.201

4.3.4.1.2 Paddy adjacent tree based land use corridor variables as independent variables

Spearman rank correlation technique was used to assess the statistical significance of vegetation richness and abundance of adjacent land use types on arthropod diversity in paddy fields. The ground (on pitfall data) and aerial arthropod (on sweep) richness and abundance were used for the correlation studies. Aerial arthropod diversity of two seasons: uncultivated (fallow) and crop season were analyzed.

The influence of adjacent land use vegetational diversity on functional guilds, such as predators, parasitoids, and pests (only *C. medinalis*) in the paddy fields were also analyzed separately. Total species richness and abundance of spiders, ground beetles of fallows, parasitic wasps, and abundance of *C. medinalis* in the crop season paddy fields were used for the analysis.

Table 4.11 Spearman rank order correlation between surrounding landuse ground floral diversity (abundance & richness) and arthropod diversity in paddy fields.

	Corridor Stand density	Corridor stand richness
Sweep abundance (uncult. season)	-0.196	0.04
Sweep richness (uncult. season)	-0.164	0.124
Pitfall abundance (uncult. season)	-0.197	-0.175
Pitfall richness (uncult. season)	-0.37	0.029
Sweep abundance (crop season)	0.103	0.203
Sweep richness (crop season)	0.089	0.268

The results have shown that the floral diversity of the adjacent corridors doesn't influence the arthropod diversity in the paddy fields, both in crop and uncultivated season. Furthermore, a significant negative correlation was observed between corridor vegetation abundance and ground arthropod richness of paddy fields ($t_{38} = -2.45$, $P = 0.04$).

Although it was not significant, the correlation between aerial arthropod diversity of the crop season paddy land and Corridor floral diversity was relatively high, and positive, it can be assumed that the corridor influences the distribution of aerial arthropod of crop season paddy land (See Table 4.11 for more details). However, the correlation between corridor stand richness and aerial arthropod richness of crop season paddy was weakly associated ($t_{37} = 1.69, P = 0.09$).

On functional guilds, except the positive correlation between ground beetle abundance and vegetation stand density of corridors ($t_{38} = 2.01, P = 0.05$) no other functional guilds were significantly influenced by the Corridor floral diversity, including a major pest of paddy, *C. medinalis*. However, a weak correlation between parasitoid richness of crop paddy lands and floral richness of corridors was noted ($t_{35} = 1.642, P = 0.1$), See Table 4.12 for more details.

Table 4.12 Spearman rank order correlation between corridor ground floral diversity (abundance & richness) and functional guilds of paddy fields.

	Corridor Stand density	Corridor stand richness
Carabid abundance (uncult. Paddy)	0.311	0.077
Carabid richness (uncult. Paddy)	0.145	-0.247
Ground spider abund. (uncult. Paddy)	-0.213	0.197
Ground spider richn. (uncult. Paddy)	-0.066	0.203
Parasitoid abundance (Crop Paddy)	0.057	0.157
Parasitoid richness (Crop Paddy)	0.049	0.267
<i>C. medinalis</i> abundance (Crop Paddy)	-0.064	0.026

4.3.4.1.3 Crop season paddy field bunds as independent variables

Irrigated paddy fields will be having bunds of various shapes, and sizes, mainly to channel water during crop season. Unless weeding is done, the bunds in the paddy fields will usually be having a wide range of wild herbs, and grasses. In this study, the impact of the floral diversity (abundance and richness) of bunds on arthropod diversity of paddy lands in two seasons (crop and uncultivated) was assessed using Spearman rank order correlation. The Table 4.13 below illustrates the correlation between floral diversity of bunds and arthropods of paddy fields. The entire ground arthropods, aerial arthropods collected on sweeping across seasons, functional guilds like predatory Carabid beetles & spiders of fallows, and parasitic wasps and *C. medinalis* abundance of the crop season were used in the analysis.

The correlation matrix has shown that except for the entire ground arthropod abundance on pitfall collection, and ground beetle (Carabid) diversity, the bund floral abundance had a negative impact on arthropod diversity of paddy fields. This reverse effect was significant too for the distribution of total aerial arthropod species richness (sweep richness), and also for the parasitoid diversity of the crop season paddy fields. However, vegetation richness in the bunds was positively correlated to the arthropod diversity of paddy fields of both the seasons, except on the pitfall capture, where the impact of bund floral richness was the opposite. From the overall analysis it was understood that ground spiders of fallows were highly associated to the floral diversity of bunds. The correlation between bund floral richness and spider richness and spider abundance of fallows was 50 and 48 percent respectively. (See Table 4.13 for more details on percent of correlations, and significance).

Table 4.13 Spearman rank order correlation between paddy field bund floral diversity (abundance & richness) and functional guilds of paddy fields.

	Bund floral abundance	Bund floral richness
Sweep abundance (uncult.season)	-0.242	-0.227
Sweep richness (uncult. season)	-0.284	-0.154
Pitfall abundance (uncult. season)	0.214	0.084
Pitfall richness (uncult season)	-0.165	0.405*
Sweep abundance (crop season)	-0.365*	0.384*
Sweep richness (crop season)	-0.25	0.295
Carabid abundance (uncult. Paddy)	0.154	0.027
Carabid richness (uncult. Paddy)	0.275	0.018
Ground spider abund. (uncult. Paddy)	-0.135	0.482**
Ground spider richn. (uncult. Paddy)	-0.095	0.509***
Parasitoid abundance (Crop Paddy)	-0.420*	0.355*
Parasitoid richness (Crop Paddy)	-0.359*	0.307*
<i>C. medinalis</i> abundance (Crop Paddy)	-0.109	0.186

*** $P < 0.0009$; ** $P < 0.005$; * $P < 0.05$

4.3.4.2 REGRESSION ANALYSIS

4.3.4.2.1 Fallow arthropods as dependant variables

Step wise multiple linear regression analysis (P to enter = 0.15) was used to find out the best predictors of arthropod diversity of paddy fields. Independent variables were grouped into four sets of logically interrelated variables: (1) microclimatic variables in

the form of soil variables (Average soil P_2O_5 (Kg./Ac), pH of soil, percent Organic Carbon (% OC), Average soil temperature, Average soil Humidity), (2) vegetation structural variables of off-season paddy lands (Stand richness, stand abundance, and percent grass cover, and (3) vegetation attributes of corridors (Stand richness and Stand abundance), and (4) vegetation attributes of bunds. The variables in each independent variable group were plotted in a scatter diagram to see the best fit of the data. All variables used in this analysis were linearly related to each other. Regression analysis results described below are summarized in Table 4.14 below.

4.6.4.2.1.1. Microclimatic attributes of fallow lands as independent variables

When microclimatic soil parameters were the independent variables, multiple regression model with forward stepwise selection showed that the total number of plants (vegetation abundance) in the paddy fields was significantly negatively associated with the Av. P_2O_5 content of the soil, and the model predicted a significant regression ($R^2 = 24\%$, $F_{3,28} = 2.98$, $P < 0.04$) with a combination of soil variables like Av. P_2O_5 ($t_{28} = -2.09$, $P = 0.04$), % OC ($t_{28} = 1.63$, $P = 0.1$); and Av. Soil Humidity ($t_{28} = 1.43$, $P = 0.1$). However the stepwise regression model has eliminated other two variables, pH and Av. soil temperature, from predicting the vegetation abundance in the paddy fields. In contrast to that, most of the variation in the distribution of floral (vegetation) richness in the paddy field was attributable to the % OC content of the soil ($R^2 = 24.1\%$, $F_{2,29} = 4.60$, $P < 0.01$) rather than any other parameters. Nevertheless, the parameters, % OC ($t_{29} = 0.37$, $P = 0.02$) and Av. Soil humidity ($t_{29} = 1.99$, $P = 0.05$) had a significant effect on the distribution of the floral richness in the fallow.

The stepwise multiple regression analysis has ruled out the influence of all of the above mentioned microclimatic variables, as none of these variables explained the variation in the ground arthropod abundance of fallows. The regression was insignificant ($R^2 = 2\%$; $F_{5,26} = 0.154$, $P = 0.9$). Meanwhile, the Av. P_2O_5 content of the soil negatively influenced the ground arthropod richness ($t_{30} = -1.5$, $P = 0.1$). Overall, the ground arthropod richness was only weakly related to microclimatic variables ($R^2 = 7\%$; $F_{1,30} = 0.154$, $P = 0.1$).

The distribution of fallow specialist Carabid beetles was inversely related to the microclimate variables. Regression analysis identified three soil variables (Av. Soil humidity, Av. P₂O₅, Av. Soil Temperature) from the list of five, to explain a significant proportion of variation ($R^2 = 20\%$; $F_{3,28} = 2.4$, $P = 0.8$) in the Carabid abundance of the fallows. Although these three variables together have explained the variation in the data, Av. Soil humidity ($t_{28} = -2.21$, $P = 0.03$), and Av. P₂O₅ had an almost strong negative impact ($t_{28} = -1.7$, $P = 0.08$) on the Carabid abundance of the fallows. Although, the influence of Av. Soil Temperature, was considered to explain the variation in the data, the impact due to this variable was not significant ($t_{28} = -1.0$, $P = 0.3$). On spider abundance, multiple linear regression was insignificant for the microclimate variables, and stepwise regression analysis has selected only two variables, Av. Soil Humidity and Soil Temperature, and explained 9 % of variation in the data ($F_{2,29} = 1.47$, $P = 0.2$). But, the spider species richness in the fallows was not attributed to any of the microclimate variables, and the regression analysis found only Av. Soil humidity ($t_{30} = 1.24$, $P = 0.2$), to have a weak relationship with the ground spider species richness, and has eliminated all other four soil variables from the list to predict the ground arthropod species richness of the fallows.

4.3.4.2.1.2. Fallow vegetation attributes as independent variables

The analysis with vegetation attributes (% grass cover, stand density, and stand richness) of the fallows as independent variables had shown that percent of grass cover in the fallow could be a significant parameter for the distribution of ground arthropods ($t_{29} = 1.7$, $P = 0.09$) rather than any other variables. The ground arthropod abundance was negatively associated to the vegetation stand richness in the paddy field, and was weakly significant ($t_{29} = -1.4$, $P = 0.15$). The stepwise regression has ruled out the influence of the vegetation abundance on ground arthropod abundance of fallows. The ANOVA results have shown that the whole regression was insignificant ($R^2 = 9\%$; $F_{2,29} = 1.60$, $P = 0.21$). The best model ($R^2 = 20\%$; $F_{2,29} = 3.75$, $P = 0.03$) predicted the ground arthropod richness of fallows was due to a combination of attributes, % grass cover ($t_{29} = 1.2$, $P = 0.2$) and vegetation abundance ($t_{29} = 1.5$, $P = 0.14$). However, the percent of regression decreased ($R^2 = 16.4\%$; $F_{1,30} = 5.90$, $P = 0.02$), when the vegetation abundance alone determines the ground arthropod richness. Meanwhile, the stepwise regression

analysis has eliminated the influence of vegetation richness on the distribution of ground arthropod species of paddy fields.

Most of the variation in the distribution of aerial arthropods of fallows was weakly explained by the vegetation stand density alone ($t_{28} = 1.61$, $P = 0.1$), and the regression was weakly significant at this level ($R^2 = 8\%$; $F_{1, 28} = 2.60$, $P = < 0.1$). The influence of other two attributes, vegetation richness and % grass cover were ruled out in the stepwise regression analysis. Meanwhile, the variation in the distribution of aerial arthropod richness was attributable to the vegetation stand density ($t_{27} = 1.5$, $P = 0.1$), and % of grass cover ($t_{27} = 1.3$, $P = 0.1$). The regression was significant, $R^2 = 23\%$; $F_{2, 27} = 4.17$, $P = < 0.02$, and the impact of vegetation richness was ruled out in the analysis. At the same time, the stepwise regression analysis brought out the importance of the vegetation abundance of paddy field, to explain a variation of 18% ($F_{1, 28} = 6.42$, $P = 0.01$) in the aerial arthropod richness. As in aerial arthropod abundance, the influence of vegetation stand richness also got eliminated in the way of stepwise regression analysis.

The regression analysis was also conducted for major predatory arthropods like Carabid beetles and spiders available in the fallows. Similar to correlation studies, the regression analysis also has predicted the significant negative relationship of stem density and richness of the fallows on Carabid abundance ($R^2 = 22\%$; $F_{2, 29} = 4.17$, $P = < 0.02$), where rather than vegetation density, the stepwise regression predicts that stem richness of the paddy field ($t_{30} = -2.6$, $P = 0.01$) could alone explain nearly 18 % of the Carabid abundance in the paddy fields (but in inverse fashion). Meanwhile, the regression predicts that Carabid richness in the fallows was not predicted by any of the concerned vegetation attributes of the paddy field ($R^2 = 2\%$; $F_{3, 28} = 0.22$, $P = < 0.8$). However, the distribution of ground spider density was positively related to the vegetation attributes of the fallows, and the regression analysis singled out the vegetation abundance ($t_{30} = 3.0$, $P = 0.005$) among the three attributes as the significant variable to explain a good proportion of the variation in the distribution of ground spider abundance ($R^2 = 23\%$; $F_{1, 30} = 9.04$, $P = < 0.005$). The regression analysis also has identified the importance of Vegetation abundance ($t_{30} = 2.64$, $P = 0.01$) of the fallows as a significant attribute to describe 18 % ($F_{1, 30} = 6.9$, $P = < 0.01$) variation of spider species richness.

4.3.4.2.1.3. Land use corridor vegetation parameters as independent variables

The corridor floral diversity was measured by the plant species richness, and abundance at the lower strata level. The distribution of whole ground arthropods, aerial arthropods of two seasons, and major functional groups of the paddy fields of both seasons were selected as dependant variables to identify the significant relationship with corridor stand diversity.

The regression analysis predicted almost no influence of vegetation diversity of corridor substrata on ground arthropod abundance and richness of the fallows. Although not significant ($R^2 = 3\%$; $F_{1, 38} = 1.52$, $P = < 0.2$), a reverse relationship between corridor stand density and ground arthropod abundance ($t_{38} = -1.22$, $P = 0.2$) was found. It was the same case for ground arthropod richness too, where corridor vegetation abundance had a significant reverse relationship with the ground arthropod richness of fallow lands. The model has explained only 13 % of the total variation in the data ($F_{1, 38} = 5.73$, $P = < 0.02$), and although reverse, the corridor vegetation abundance ($t_{38} = -2.39$, $P = 0.02$) alone explained this much variation and which was significant too. The response of aerial arthropod abundance ($t_{35} = -1.42$, $P = 0.1$) and richness ($t_{35} = -1.66$, $P = 0.1$) in the fallow was negative with the corridor stem density, and in both the cases it had a significant role too to explain the total variation in the data, along with stem richness of the corridor ($t_{35} = 0.58$, $P = 0.5$ NS, and $t_{35} = 1.37$, $P = 0.1$, for aerial arthropod abundance and richness respectively). Both the variables together had explained a total variation of only 5 and 9 % of the aerial arthropod abundance ($F_{2, 35} = 1.02$, $P = < 0.3$) and richness ($F_{2, 35} = 1.76$, $P = < 0.2$) of the fallow lands, and were not significant.

On functional guilds of fallow, the regression was weakly significant on the corridor vegetation diversity. For Carabid abundance in fallows, the model has explained 4 % of total variation ($F_{1, 38} = 1.97$, $P = < 0.16$) of the data only by corridor stand density. The regression analysis has eliminated the role of corridor vegetation richness from the model. However, the influence of vegetation attributes on carabid richness in the paddy fields was mixed, corridor richness had a strong negative impact ($t_{37} = -1.85$, $P = 0.07$), and stem density had a positive impact ($t_{37} = 1.36$, $P = 0.17$), and together the model had explained 10 % of the total variation in the data ($F_{2, 37} = 2.27$, $P = < 0.01$). In contrast, the influence of corridor diversity was insignificant on the spider diversity of the fallows. For

spider abundance, the regression analysis has eliminated both the attributes of the corridor from explaining the variation in the data; for the spider richness, though corridor vegetation richness had explained 3 % of the variation, the regression was insignificant ($F_{1, 38} = 1.45, P = < 0.23$).

4.3.4.2.2 Crop Season Paddy arthropod measures as dependant variables

In the crop season, the analysis was conducted for the whole aerial arthropod diversity, particularly for the parasitic wasps, and *C. medinalis* of the cultivated paddy lands. For both whole aerial arthropod abundance, and parasitoid abundance in the paddy fields, regression analysis has predicted the absence of any role of corridor stem diversity (both richness and abundance) to explain the variation in the data. Meanwhile, the whole arthropod richness ($t_{35} = 1.58, P = 0.12$) and parasitoid richness ($t_{35} = 1.31, P = 0.2$) were positively related to the corridor stand richness, and regression analysis has eliminated the role of corridor stem density in explaining the species richness of these insects in the cultivated paddy fields. The regression analysis explained 6 and 4 % of the variation in the distribution of whole arthropod and parasitic wasp richness of the cultivated paddy fields, at $F_{1, 35} = 2.50, P = < 0.12$, and $F_{1, 35} = 1.72, P = < 0.2$ respectively. The regression analysis has predicted no effect of corridor underground vegetation diversity on *C. medinalis* distribution in the cultivated paddy fields ($R^2 = 1\%; F_{2, 37} = 0.27, P = 0.7$).

4.3.4.2.3 Impact of Vegetation diversity of paddy field bunds on arthropod diversity of crop season paddy fields and fallow lands

The vegetation diversity of the paddy bunds was assessed toward the end of the cultivation season, in November 2004. The analysis at all levels, whole ground and aerial arthropod diversity of both the seasons and major functional groups of paddy fields were conducted.

Very surprisingly, for the entire crop season arthropod data, the bund stand density appeared to be negatively related, and in most cases this reverse impact had a significant impact too to explain the major proportion of the variation in the data. Multiple regression models showed that the total number ($R^2 = 25\%; F_{2, 33} = 5.61, P = < 0.007$), and total species richness ($R^2 = 21\%; F_{2, 33} = 4.65, P = < 0.01$) of aerial arthropods collected on sweep samples from the paddy fields were positively, and significantly

associated with the increased stem richness in the bunds. In both the cases, most of the variation was attributed to the bund vegetation richness ($t_{33} = 2.77$, $P = 0.008$, and $t_{33} = 2.35$, $P = 0.02$ respectively for arthropod abundance and richness) rather than vegetation abundance ($t_{33} = -1.93$, $P = 0.06$, and $t_{33} = -1.98$, $P = 0.05$). It was the same case for the parasitoid data too. Stem density as well as stem species richness together had explained a significant proportion of the variation in the abundance ($R^2 = 21\%$; $F_{2, 33} = 4.56$, $P < 0.01$) and richness ($R^2 = 20\%$; $F_{2, 33} = 4.29$, $P < 0.02$) of parasitic wasps of the crop season paddy fields. However, both the parasitoid abundance and richness were significantly decreasing with the increasing stem density of the bunds ($t_{33} = -1.83$, $P = 0.07$, and $t_{33} = -1.89$, $P = 0.06$), but was increasing with the increasing floral richness of bunds ($t_{33} = 2.43$, $P = 0.02$, and $t_{33} = 2.27$, $P = 0.02$).

The results of multiple regression analysis showed that bund floral diversity could also be a crucial parameter to explain a major proportion of arthropods of the fallows too. Multiple regression models suggested that 15 % of the total variation of the ground arthropod richness as on pitfall traps was attributable to the floral richness of bunds ($F_{1, 35} = 6.36$, $P < 0.01$), and eliminated the stem density of bunds from the model. Meanwhile, the analysis had nullified the role of bund vegetation diversity on total number of ground arthropods collected from the fallow lands. The regression model also demonstrated that the aerial arthropod diversity of the fallows was decreasing with increasing floral diversity of bunds. However, the regression was significant at $P = 0.1$ for both total aerial arthropod number and richness (See Table for more details on t values and significances).

In the entire data, ground spiders of fallows would be the only functional group that could be more benefited from the increasing floral diversity of bunds. The regression model suggests that most of the variation in the distribution of ground active spiders was more attributable to the floral richness ($t_{36} = 4.24$, $P = 0.0001$) of the bunds, rather than the vegetation abundance ($t_{36} = 1.46$, $P = 0.1$). Nevertheless, both the parameters had explained 36 % of the total variation ($F_{2, 36} = 10.28$, $P < 0.0002$) in the spider richness of fallows. While, the variation in the spider abundance of fallow was attributable only to –

Table 4.14 Multiple-linear regression analyses of relationships between fallow vegetation variables and microclimate variables, and arthropod diversity vs. microclimate and fallow vegetation variables

	Microclimate variables			Fallow vegetation attributes				
	R ² (%)	Av. P2O5%	OC	Av. Soil Hum	R ² (%)	% grass	Stand density	Stand Richness
Vegetation								
Stand density (Fallows)	24**	-0.35**	0.27*	0.24*				
Stand richness (Fallows)	24.1**		0.37**	0.32**				
Ground arthropods								
Abundance	2				9	0.36*		-0.28*
Richness	7*	-0.27*			20**	0.23	0.28*	
Major Functional groups								
Carabid abundance	20	-0.3*		-0.44**	22**		-0.24	-0.29**
Carabid richness	2				2			
Spider abundance	9			0.35	23***		0.48***	
Spider richness	4			0.22	18**		0.43**	
Aerial arthropods								
Abundance					8*		0.29*	
Richness					23**	0.26*	0.29*	

	Corridor vegetation variables			Bund Vegetation variables		
	R ² (%)	Stand density	Stand richness	R ² (%)	Stand density	Stand richness
CROP SEASON PADDY FIELD						
Aerial arthropods						
Abundance	0			25**	-0.29*	0.41**
Richness	6*		0.25*	21**	-0.3**	0.36**
Major Functional groups						
Parasitic wasp abundance	0			21**	-0.28*	0.37**
Parasitic wasp richness	4		0.21*	20**	-0.29*	0.35**
FALLOWS						
Ground arthropods						
Abundance	3			3		
Richness	13**	-0.36**		15**		0.39**
Major Functional groups						
Carabid abundance	4	0.22		0		
Carabid richness	10**	0.21	-0.29**	7*	0.26*	
Spider abundance	10	-0.27*	0.23*	14**		0.38**
Spider richness	3		0.19	36****	0.19	0.56****
Aerial arthropods						
Abundance	5	-0.24*		10*	-0.24*	-0.19
Richness	9	-0.28*	0.23*	7*	-0.26*	

Significant beta * $P < 0.15$, ** $P < 0.05$, *** $P < 0.005$, **** $P < 0.0$

the floral species richness of the bunds ($F_{1, 37} = 6.52, P < 0.01$), which has explained 14 % of total variation in the data. However, the importance of bund floral diversity in the distribution of carabid species of fallows was weak, only 7 % of the data was explained by this attribute ($F_{1, 37} = 2.82, P < 0.10$). Meanwhile, the model has ruled out the influence of bund floral diversity in the distribution of total number of carabid individuals of fallow lands. The regression analysis also has ruled out the influence of bund vegetation diversity on paddy pest, *C. medinalis* population build up in crop season paddy fields ($R^2 = 2\%$; $F_{2, 36} = 0.36, P = 0.7$). See Table 4.14 for summary of the Regression analysis.

4.4 DISCUSSION

4.4.1 IMPACT OF STAND SIMPLIFICATION IN THE ADJACENT LAND USE TYPES ON ARTHROPOD, FLORAL DIVERSITY AND PRODUCTIVITY OF RICE PADDY LANDS OF SRINGERI

Although it was not significant, a discernible impact of the stand simplification in the adjacent land use types was noted on floral and faunal diversity of rice paddy agro – ecosystems of Sringeri landscape. However, the diversity of arthropod fauna of paddy fields was different for the fallow and cultivation period, and also between ground and aerial arthropods

In the fallows adjacent to heterogeneous *Soppinabetta* forests (SBPaddy) the diversity of both ground as well as arboreal arthropod community was more, and diversity was least in the fallows adjacent to the highly simplified Acacia plantations (ACPaddy). This finding supports the natural enemy hypothesis (Root 1973) to a certain extent, or at least for the fallow period, and agrees with several other studies (Risch et al. 1983, Luczak 1979, Russell 1989, Letourneau 1986, Marino and Landis 1996, Andow 1990, Speight and Lawton 1976, Sheehan 1986, Kemp and Barret 1989, Murphy 1994, Corbett and Rosenheim 1996). The lower strata floral diversity of corridor habitats also was lowest in Acacia plantations (See Table 4.15). Whereas, Areca dominated rice agro – landscape (ARPaddy) showed more arthropod diversity in terms of species richness and abundance. Although Degraded Scrub forest (DS) was relatively more diverse on lower strata flora, the difference with Areca Orchard (AR) was negligible (Table 4.15).

However, when the floral diversity of fallows was estimated during arthropod sampling, paddy fields adjacent to AR (ARPaddy) showed maximum diversity, followed by the SBPaddy; DSPaddy was the least on floral species richness (See Table 4.2 in Results).

Table 4.15 Comparison of lower strata floral diversity of four land use types

	Shannon	Abundance	Richness
SB	3.43	1383	84
DS	3.20	1451	65
AR	3.02	1406	61
AC	2.58	806	35

It is assumed that the arthropod diversity of the paddy fields was determined jointly by the floral diversity of within and surrounding areas of agro – landscapes. Several studies have reported the importance of maintaining stand diversity within agro – ecosystem, either by the intermixed crop varieties or by the wild relatives of the crop plants (Kemp and Barrett 1989, Altieri et al. 1987, McLachlan and Wratten 2003, Riechert and Bishop 1990, Luczak 1979, Corbett and Plant 1993).

On another hand, generalist predatory arthropods like Carabid beetles and ground dwelling spider community were captured more in the fallows adjacent to simplified corridor habitats like AC and DS (See Box plot, Figures 4.4 and 4.5), relative to complex agro - landscapes. This also can be attributed to the floral diversity of within rice paddy agro – ecosystems; apparently, fallows adjacent to AC were least abundant on flora, and were with more or less open ground. Southwood (1962) also reported that Spiders and Carabid beetles are the pioneers of any disturbed or modified habitat due to their high dispersal power, and their generalist nature. In this study, multiple linear regression results strengthen the role of within and surrounding habitat heterogeneity in determining the ground beetle and spider community. Both the functional groups were highly correlated to the stem diversity of fallows rather than the diversity of the surrounding land use types. But a slight change in the microhabitat requirements for spiders and ground beetles was observed; spider density and richness were increasing with the floral diversity of the fallow lands and surrounding uncultivated area, whereas Carabid beetle density appeared to decrease with the increasing stand diversity of the landscape and fallows. However, Carabid density was more diverse in the fallows adjacent to SB forest,

and was least in the paddy fallows adjacent to AC plantations (See Box plot, Figure 4.4). While, spider abundance remained more abundant in the fallows close to AR.

On the other hand, aerial insects showed a different relationship to the adjacent land use types; fallows adjacent to AR corridor (AR Paddy) was most diverse, followed by SB Paddy. Meantime, DS adjacent fallows (DSPaddy) appeared least diverse in aerial arthropods in the off-season. This again can be justified by the reason that paddy fields adjacent to AR orchard were most diverse in floral species richness and abundance, which not only provide nectar sources for the adult male and female wasps, but also provide alternative ovipositional sites too. Regression analysis predicted that within fallow vegetation diversity, rather than surrounding habitat and bund diversity, to be the important parameter for determining the aerial arthropod diversity of fallows in the uncultivated season. However, a slight positive correlation was found between the corridor lower strata floral richness and aerial arthropod, and parasitoid richness of crop season paddy fields and fallows. But, the stand density of the surrounding areas appeared

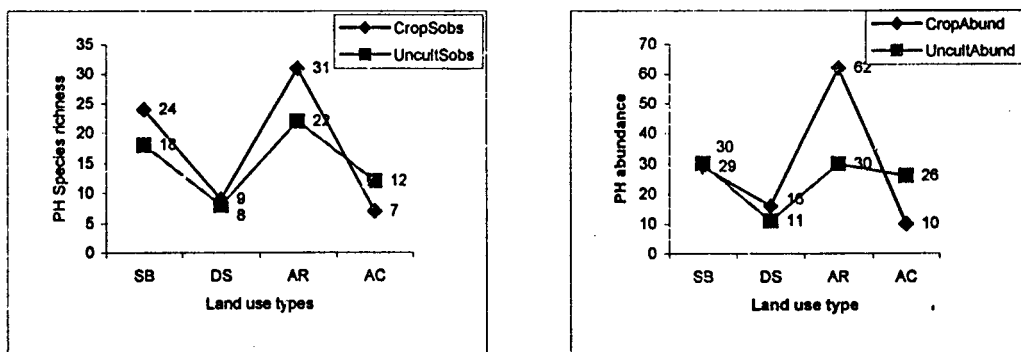


Figure 4.21 Parasitic Hymenopteran (PH) species richness and abundance inside various land use corridors adjacent to fallows and cultivated paddy fields

to have no effect or a considerable negative role for determining the activity of aerial arthropod diversity inside fallows. This finding again shows the importance in maintaining within stand diversity for the arthropod conservation.

Aerial arthropod diversity of cultivated paddy fields showed a different relationship with the heterogeneity of the adjacent land use corridor habitats. Paddy fields adjacent to DS (DSPaddy) attracted more flying arthropods, which was followed by the

ACPaddy. Parasitoid diversity also gave a similar result. These findings may contradict the natural enemy hypothesis, but the one reason, which could underpin this particular finding would be, the presence of moderately floral rich paddy bunds in DSPaddy agro – landscape.

Regression analysis also predicted that floral richness of paddy bunds, rather than the stand diversity of the surrounding land use types had a significant positive impact on the total aerial arthropods as well as parasitoid diversity of the crop season paddy fields (See Regression results, Table 4.14). However, the reason, why arthropods in general, and parasitoids in particular are more diverse in the paddy fields adjacent to AC plantation was not clear. However, from the box plot (Figure 4.6), it was almost clear that although median richness and abundance of whole aerial arthropods and parasitoids of ARPaddy and SBPaddy were relatively less, a good source of variation exists in the paddy fields adjacent to ARPaddy. Interestingly, when parasitoid diversity of the corridor habitats was analysed, AR and SB appeared most diverse, when compared to other two habitats: AC and DS, which were least diverse in parasitoid community, both in off and crop seasons (See Figure 4.21). This can be correlated to the similarity results, where AC and DS corridors were separated out, and were least similar to the paddy fields of the crop season (See dendrogram Figure 13). The inference is, though ARPaddy and SBPaddy were relatively least diverse on PH community, a good proportion of the parasitoid movement to the paddy fields occurs from these corridor habitats, rather than from DS and AC corridor habitats. This way, the study supports the natural enemy hypothesis to a certain extent.

The floral rich paddy bunds were the reservoirs of the ground arthropods, and particularly for the generalist predatory arthropods in the fallow period. Regression analysis explicitly showed that paddy field bund floral diversity was one of the most important parameter for the diversity of the spider community of rice paddy agro – ecosystems (See Regression Table 4.14). Thomas et al (1991), Chiverton (1989), Collins et al. (2002), Thomas et al (2000), MacLeod et al. (1992), Carmona & Landis (1999), Berry (1997), Speight & Lawton (1976), Corbett & Plant (1993) also have showed the importance of the ‘beetle banks’, ‘island habitats’, or weed cover inside the agro – ecosystems to maintain diverse polyphagous arthropod predator populations. A study by

Afun et al. (1999) demonstrated the importance in placing weed residues within the rice fields in maintaining the spider densities of upland rice ecosystems. In this study, results indicate that floral rich paddy bunds were not only important to maintain a good population of predatory carabid beetles and spider community, but also were important for maintaining parasitoid species diversity of the crop season paddy fields. Sigsgaard et al. (1999), and Sigsgaard (2000) also illustrated the role of paddy bunds in maintaining population density of spiders of fallows and croplands. Floral richness of bunds, not floral abundance had a positive significant impact on the aerial arthropods, and particularly parasitoid diversity of crop season paddy fields. So the study inferred that maintaining diverse paddy bunds, rather than single species dense paddy bunds has a potential role in conserving natural enemy population of rice paddy agro – ecosystems.

The stand simplification in the adjacent land use types has a significant impact on pest density too, and was apparent in *C. medinalis* (rice leaf roller) population outbreak in the rice paddy agro – ecosystems of Sringeri. The study showed that pest abundance as well infestation rate due to *C. medinalis* was at its maximum in the rice paddy lands adjacent to AC plantations, and was least in the paddy adjacent to heterogeneous SB forests (See Box plot, Figure 4.7). The particular finding endorses the natural enemy hypothesis (Root 1973), and agrees with several other study results, like Risch et al. (1983), Andow (1990), Horn (1981).

Although, the present study underlined the importance of maintaining wild floral diversity in rice paddy agro – landscapes, to preserve natural biological control agents, the relative lower yield from the paddy fields, margined by heterogeneous corridor habitats, raises concern about the economic feasibility of doing it. The box plots (Figure 4.8) showed that median grain count (precise data), and grain weight / sq m. were more in the paddy fields adjacent to AR orchards and reduced in the following manner: ARPaddy > AC Paddy > DSPaddy > SBPaddy. However, the study leaves a serious question unanswered that is, whether it is the heterogeneous tree diversity rather than the lower level herbaceous diversity that affects the natural enemy population of rice paddy agro – ecosystems? In the present study, natural enemy hypothesis was proved partially true, if the lower level herbaceous diversity is taken into account, which was more diverse in the AR orchard too. Meanwhile, the study suggests that management of the heterogeneity

within agro – ecosystems is more or less equally important in maintaining the heterogeneity of the surrounding landscapes.

The results suggest that soil microclimate does not influence the ground arthropod diversity in any way. The richness of Spider community during crop season cannot be explained by any of soil variables. The negative influence of Av. P2O5 on ground arthropod richness does point to the role of increased application of fertilizers in decreasing ground arthropod richness. Soil humidity increase also does not favour Carabid beetle abundance and richness.

4.4.2 IMPACT OF DISTANCE GRADIENT ON ARTHROPOD DIVERSITY AND RICE YIELD IN RICE PADDY AGRO – ECOSYSTEMS

Arthropod community's response to the distance from farm boundary was different during the fallow and cultivation period in the rice paddy agro – ecosystems. In fallows, both ground as well as aerial arthropods was decreasing in general, when moving away from the farm boundaries, but the difference was not statistically significant for the median species richness and abundance of arthropods. The results agree with the findings of a couple of other studies like McLachlan and Wratten (2003), Kemp and Barrett (1989). However, in the crop season, aerial arthropods in general and particularly parasitic wasps were increasing, when moving away from the land use – paddy edges in the rice paddy fields. *C. medinalis* population, as well as infestation due to this pest also was increasing with distance from the farm boundary. These results support the resource concentration hypothesis to a certain extent, because, as the distance from the paddy field edges increased, only rice plants were abundant, and intact, which lead to the increased population build up of herbivores. However, the effect of distance on aerial arthropod and parasitoid diversity, and *C. medinalis* population density remained insignificant.

The distance from the farm boundary did not have a discernible effect on the grain production, and at all distance levels the grain yield as counted per ear hill, remained almost same in the rice paddy agro – ecosystems. Whereas the difference in the grain weight per meter square increased when moving away from the farm boundary, and was statistically significant too. However, the major reason for not generalizing the results on grain weight is that, the number of saplings in one sq m was not equal, which varied

between 16 saplings to 45 per square meter. Furthermore, it was not the same cultivar type used in all the study sites. (See Table 4.16 for more details on the grain count/ear hill, weight per row sq m., and range of number of paddy plants counted per square meter). It was found that *DappaBatha* could be a promising cultivar type than others for *Malnaad* region, because of two major reasons: it is a native variety, and is less prone to the pest attack, and gave a substantial yield relative to other three hybrid varieties.

Table 4.16 Statistics of the yield: grain count, weight of grains / sq m. and the range of number of plants counted per square meter

Cultivar type	No of plants/Sq m.	Wt. Of grains (in gms)		Count of grains/ ear hill	
		Range	Average	Range	Average
<i>IET</i>	16 - 37	120 - 580	376	59 - 348	164.59
<i>Padmarekha</i>	23 - 29	350 - 460	398.33	109 - 321	230.9
<i>DappaBatha</i>	20 - 30	430 - 480	446.66	75 - 316	157.23
<i>Abhilasha</i>	45	600	600	113 - 198	162.4

4.4.3 SIMILARITY OF ARTHROPOD COMMUNITY COMPOSITION BETWEEN ADJACENT LAND USE TYPES AND RICE PADDY FIELDS OF SRINGERI RICE PADDY AGRO – LANDSCAPE

Similarity studies on arthropod community composition had drawn two major conclusions: a huge turn over in the arthropod community, particularly aerial predatory, parasitoid, and pest arthropods, occur between rice paddy fields of fallow period and cultivation period, and arthropod community of rice paddy lands are different from other tree based adjacent land use types in aerial arthropod community.

Although the cluster diagram brought out two major clusters, one exclusively for the land use corridor habitats, and other only for the fallow lands, the dendrograms on ground arthropods in general, as well as for generalist predatory groups like Carabid beetles and spider community, showed a relative good proportion of species similarity between paddy fields and other adjacent land use types. Although no mark recapture results are available, it is assumed that ground beetles and spiders do have a good dispersal power, and it is also assumed that at least some members of these two taxa are habitat generalists. The > 30 % similarity of AC plantations and fallows, and nearly 50 % similarity between AR orchard and fallow lands in ground dwelling spiders, emphasizes that movement happens more in the simple rice paddy agro – landscape, relative to complex agro – landscapes, which comprises SB and DS forests as the heterogeneous

component. The relative high similarity of ground arthropods between simplified land use corridor habitats like AC and AR, and fallow lands suggests that most of the studied plantations or monoculture habitats were the paddy converted lands.

However, the considerable similarity of active aerial arthropods, which was collected by Malaise traps, between fallow lands and other land use corridors could be due to the vagrant nature of these arthropods. Meantime, arthropods collected by sweeping had shown relatively low arthropod similarity between fallows and other land use corridors. The results credibly argue that fallow arthropod community is a different entity, and could be the permanent residents of the fallow lands.

However, the dendrogram constructed on aerial arthropods of crop season, particularly on parasitic hymenopteran (PH) community, suggests that a substantial parasitoid movement happens between adjacent land use types and cultivated paddy fields, which was most evident for AR orchard and cultivated paddy lands. Taken together, it is understood that AR orchard is the closest relative of the paddy fields, both in the crop and off seasons (See dendrogram Figure 4.12), and AC plantation is the distant relative of the paddy fields in arthropod species composition with one or two exceptional cases.

4.4.4 CONCLUSIONS

The study concludes that arthropod movement from adjacent uncultivated lands to the farmlands is totally dependant on the dispersal capability of the species, and is resource oriented too. The study also suggest that grassy corridors, rather than the heterogeneity of the woody tree species, have a discernible effect on the beneficial arthropod and pest movement and occurrence in the rice paddy agro – ecosystems of Sringeri landscape. Although an expected significant impact due to the stand simplification in the surrounding land use types was not found on arthropod community of rice paddy agro – ecosystem, the study identified the importance and need in maintaining within farm stand diversity, especially on bunds for preserving the arthropod natural enemy community, to the rice paddy lands.

Chapter 5

ROLE OF GENERALIST PREDATORS OF RICE PADDY AGRO – ECOSYSTEMS: A CASE STUDY ON TIGER BEETLES

5.1. INTRODUCTION

Arthropod predators and parasitoids are the major functional guilds of any agro – ecosystems. However, the role of polyphagous predatory arthropods of croplands has been recognized in the theme ‘biological control’, and assumed it is that they are the major natural enemies of several pests of agricultural crops. The recent interests in the creation of artificial winter refuges for the predatory beetles; made popular by the name ‘beetle banks’ (MacLeod et al 2004), throughout UK cereal fields, shows the relevance in maintaining predatory arthropods within farms. Although, a number of predatory arthropods are recorded, Carabid beetles, and Spiders are well-studied, polyphagous predatory groups of cereal agro – ecosystems. Among these two, the role of spiders in feeding and controlling arthropod pests has been proved (Schoenley et al. 1998, Barrion and Litsinger 1995, Venkateshalu 1996, Reddy 2000).

Like other agro – ecosystems, rice paddy agro – ecosystems are also rich in polyphagous predatory arthropods, and mainly comprises a number of spiders, carabid beetles, aquatic and terrestrial bugs (Veliidae, Mesoveliidae, Nabidae, Anthocoridae, Miridae, Reduviidae), dragon and damsel flies. Way & Heong (1994) and Settles et al.

(1996), demonstrated the existence of high proportion of natural biological control due to the predatory arthropods. Heong et al. (1991) identified more than 53 % of total arthropods of rice paddy lands as predators. But, they recorded Order Heteroptera as the dominant predatory group of rice paddy fields of Philippines, which was followed by spiders; a total of 46 species of polyphagous predatory arthropods were identified. The rice paddy ecosystems of Sri Lanka were also rich in predatory arthropods, and more than 50 % of the total arthropod community was predators (Bambaradeniya and Edirisinghe 2001), and Spiders were identified as the dominant predatory group. Rai et al (2000) in their compendium on the coleopteran insects of rice paddy agro – ecosystems of south and Southeast Asian countries, have recorded 66 beetle species as the predators.

In this study, 21 % and 32 % of the total arthropod community of the crop season, and off-season paddy fields were the predatory arthropods. In the fallows, Spiders were the dominant predatory group (39 species), followed by Carabidae (37 species) and Staphylinidae (17 species). Meanwhile, predatory arthropods on abundance in the reducing order was Carabidae (1679 individuals) > Spiders (773 individuals) > Staphylinidae (230 individuals). Crop season paddy fields were dominated by Spiders (10 sp, 65 individuals), and Dolichopodid flies (9 species, 251 individuals), as predatory arthropods. Whereas proportion of parasitoid species richness was relatively more than the predators, in the cultivated paddy fields, a total of 25 % of arthropods collected during this period were parasitoids, and all together 904 individuals of parasitoids were collected.

Although two species of tiger beetles (Cicindelidae) were represented in the list of predatory arthropods of crop season paddy fields, the sampling methods used didn't capture a good sample of these beetles. Incidentally, it appeared that > 80 % of the total biomass and number of individuals of predatory arthropods of the crop season paddy fields may be contributed by these two species of tiger beetles. Increasingly, it is also noted that these two species of tiger beetles were highly habitat specific too, and found in the crop season rice paddy alone and pupae over winter in the moist, wet areas of the paddy fields during fallow period. The objective of this chapter is to investigate the role of these two highly polyphagous predatory beetles in the rice paddy agro – ecosystems of

Sringeri. This study is intended to unravel the feeding ecology of these two species of tiger beetles too.

Among other major limiting resources, food can play a pivotal role in determining the life cycle, activity and co - occurrence of animal populations (Lenski 1982); a number of studies have indicated that various biotic factors, such as competition, resource availability and sharing, can be important for some insect assemblages, especially predatory insects (Lawton *et al.* 1980, Lawton and Hassell 1981, Tepedino and Stanton 1981, Juliano 1986, Juliano and Lawton 1990). Knisley & Pearson (1981) and Hori (1982) have shown that the availability of prey organisms can be the fundamental limiting factor in maintaining the life cycle and growth rate of tiger beetles. Rainfall appears to be the most obvious abiotic ecological correlate in many but not all parts of the world for the diversity of tiger beetles (Pearson and Kinsley 1985, Pearson and Ghorpade 1989, Pearson and Carroll 1998).

Overlap in habitat use and resource sharing by closely related species is an alternative to the principle of competitive exclusion proposed by Gause (1934), and it has been found widely in the herbivorous insects (Ross 1957, Broadhead 1958). Tiger beetles of various species are among the most widely studied predatory insects that are known to use the same habitat or the same microclimate niche and sometimes even partition prey organisms (Pearson and Vogler 2001).

Tiger beetles are well-known voracious insect predators that predate on a range of live small arthropods in various ecosystems (Pearson and Mury 1979, Pearson 1988, Pearson and Cassola 1992), a character that has helped to earn them the common name, 'tiger beetles'. Recent reviews, such as Pearson & Vogler (2001) and Pearson (1988), have compiled the extensive biology and foraging behavior of tiger beetles in depth. Although both larvae and adult tiger beetles are assumed to be general hunters, their strategy to capture prey organisms are entirely different; larvae are passive predators as they wait at the openings of their tunnels and ambush approaching prey (Hori 1982), while adults are fast hunters and use several iterations of stop-and-go running behind the tiny live arthropods before they capture the prey (Gilbert 1997), and mainly use the familiarity of the shape or size and location of the prey to recognize the victim

(Swiecimski 1956). On occasions, tiger beetle adults will scavenge large dead or dying organisms, or occasionally feed on fruits (Pearson and Vogler 2001).

Although several species of tiger beetles have been proposed as potential bio control agents in various agro-ecosystems around the world (Pearson 1988, Pearson and Vogler 2001), these claims are based only on a few personal observations by researchers, and few direct observational or experimental studies (Sastry and Appanna 1958, Fowler 1987, Hudson *et al.* 1988) have examined the precise role of tiger beetles in controlling pest populations. A preliminary observation in India suggested that *Cicindela flavomaculata* could be a potential bio control agent of rice paddy pests in irrigated rice fields (Pearson and Vogler 2001). Meanwhile, some other observations (Dammerman 1929, Frick 1957) have illustrated the potentially negative roles of tiger beetles, as well.

With more than 2600 species worldwide, tiger beetles (Cicindelidae: Coleoptera) occur in a broad range of habitats, except for some oceanic islands and Antarctica (Pearson 1988). *Cicindela* Linnaeus is by far the largest tiger beetle genus with approximately 875 known species worldwide; the Indian subcontinent has 151 species from 24 sub genera (Acciavatti and Pearson 1989). Adults occur in almost all major habitats that include forest grounds, plantations, stream edges, agricultural lands and ocean beaches. Although some members of this genus occasionally use undergrowth bushes as a temporary substratum, virtually all species are ground dwellers and foragers (Fowler 1912). Most of them are found to prefer open areas compared to thick evergreen forest floors.

In south India *Cicindela (Calochroa) whithilli* (Hope) and *Cicindela (Calochroa) flavomaculata* (Hope) are the two major tiger beetle species that are found together in enormous numbers in cultivated rice paddy fields (Fowler 1912). However another common species, *Cicindela (Calochroa) duponti* Dejean also commonly occurs in the sandy floors of adjacent monoculture plantations such as Areca orchards and Acacia (wattle) plantations and also on the bunds that intercepts these plantations from the cultivated rice paddy fields. We thus tested the prediction that these three tiger beetle species were significant predators of several rice paddy pests. To conduct these tests, we choose: (1) to observe the feeding ecology of *Cicindela (Calochroa) whithilli*, *Cicindela (Calochroa) flavomaculata* and *Cicindela (Calochroa) duponti* in detail by measuring

capture rate and consumption time for major prey organisms in the field (only for *C. whithilli* and *C. flavomaculata*), 2) to understand the feeding strategies of tiger beetles on earthworms and on tadpoles (other than *C. sedecimpunctata* (Pearson and Vogler 2001), no other tiger beetles are reported to feed on tadpoles), so as to redefine the feeding guild of tiger beetles, and (3) to examine the predatory potential of these three species of tiger beetles on major rice paddy pests. The study also discusses the detailed natural history of adult *C. whithilli* and *C. flavomaculata*.

5.2. METHODS

5.2.1 STUDY AREA

The study was conducted in the paddy fields of Sringeri. Eight rice paddy fields from eight hamlets (Figure 5.1), which were following the traditional farming practice (no pesticide usage) for past five years before the study year, were selected for the field observations. The study was conducted from March 2003 – October 2004.

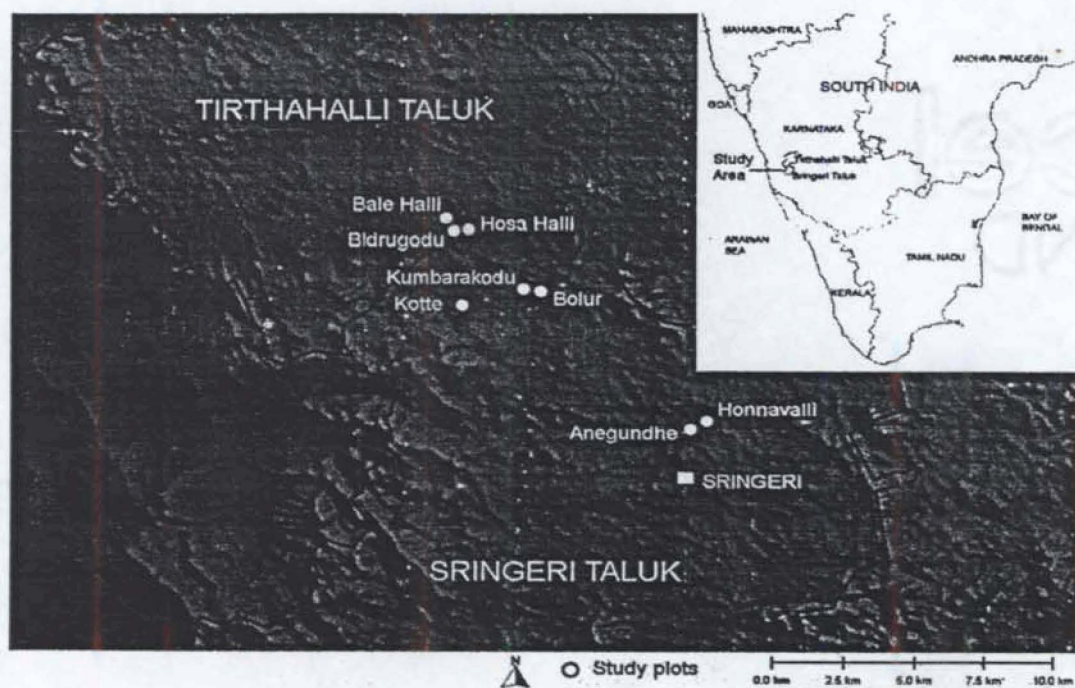


Fig. 5.1 Map showing selected field sites

5.2.2 NATURAL HISTORY OF TIGER BEETLES IN SRINGERI

We recorded 8 species of tiger beetles from various habitats on or adjacent to the study sites; six species belong to the genus *Cicindela* Linnaeus and one species each from the genera *Collyris* Fab. and *Rhytidophaena* Bates. All species, except the arboreal *Collyris* sp., were found on the floor of one or more habitat types; *Cicindela (Calochroa) whithilli* and *Cicindela (Calochroa) flavomaculata* were the two most abundant species in the area and the only tiger beetle species encountered in the cultivated rice paddy fields in Sringeri. Both the species usually co-occur in their feeding ground as an intact assemblage and share food resources. *Cicindela (Cosmodela) duponti* Dejean was the third common species observed in Sringeri area and occurred in large numbers on sandy floors of Areca orchards, other tree based plantations like Acacia plantations and occasionally in association with *Cicindela (Calochroa) fabriciana* Horn on forest paths. Unlike *C. whithilli* and *C. flavomaculata* that frequently congregate together in large numbers, individuals of *C. duponti* were more solitary in their feeding habitat. Although, *C. duponti* was common on bunds that separate Areca gardens from paddy fields, their activities never extended into paddy fields, even when disturbed. *Cicindela (Ancyliia) andrewsi* (Horn) is sighted rarely in Sringeri and found to occur on forest paths. *Cicindela (Eugrapha) minuta* Olivier and *Rhytidophaena sp.* are riparian and occupy sandy banks of streams and other water bodies. Adult *C. minuta* were active on the banks of streams throughout the year, while all other species were highly seasonal. *Cicindela whithilli*, *C. flavomaculata* and *Collyris sp.* were active from June – December; the adults of all the other beetles were active between June and October (the period with high precipitation). All the tiger beetles are identified using Acciavatti & Pearson (1989), and their identities confirmed by voucher specimens available at the Department of Entomology, University of Agricultural Sciences, GKVK, Bangalore.

5.2.3 ABUNDANCE OF *C. WHITHILLI* AND *C. FLAVOMACULATA* ACROSS SEASONS

Eight rice paddy fields were selected in various villages (Figure 5.1) of Sringeri taluk, and a single transect of 10 X 5 m was laid from one edge towards the center in each rice paddy field. Relative abundance of *C. whithilli* and *C. flavomaculata* was estimated with a visual census in each of these transects during a 30 min walk. The counts were taken during two different periods of a crop season – immediately after ploughing (late May),

and 30 days after seedling transplantation (early October). The number of individuals of both the species was plotted for each study site and later the abundance of each species pooled across study sites and the average value calculated for both the seasons.

5.2.4 PREY PREFERENCE AND FORAGING STRATEGIES OF ADULT TIGER BEETLES

Foraging behavior of *C. whithilli*, *C. flavomaculata* and *C. duponti* was studied from all the eight study sites. All three species were most active during forenoon; hence field observations were restricted in each study site from 0700 to 1300 hr. Maximum care was taken not to disturb the natural activities of the adult tiger beetles. The foraging strategies of *C. whithilli* and *C. flavomaculata* on earthworms and tadpoles were studied in detail. A selected number of beetles (N in Table 5.1 & 5.2) of both the species were tracked carefully for one hour to quantify and compare the capture rate (number of preys captured per one hour), and consumption time (time required to consume each prey organism) for preferred prey organisms like tadpoles, earthworms and ants. Non-parametric Kruskal-Wallis ANOVA was conducted to compare the difference in median capture rate of tiger beetle species. The median consumption time of earthworms and tadpoles between tiger beetle species were compared by Mann-Whitney U test. Both captured and attempted capture of preys were recorded and identified to possible lower taxon. An attempt has also been made to photographically document major predatory actions (See Plate 8). Other feeding and post feeding behaviors and predators of *C. whithilli* and *C. flavomaculata* that were encountered during the course of field survey are also discussed.

5.3 RESULTS

5.3.1 ABUNDANCE OF *C. WHITHILLI* AND *C. FLAVOMACULATA* ACROSS SEASONS

A major decline in the abundance of *C. whithilli* and *C. flavomaculata* is noted towards the latter period of their adult activity in all the eight study sites (Figure 5.2); *C. whithilli* was found to decrease from an average of 23 individuals per transect in the early season to 12.25 towards the midseason and *C. flavomaculata* was found to decrease from an average of 8.75 individuals to 2 towards the mid season. However two study sites (Bale Halli and Honnavalli), which were deserted earlier by these beetles, were later found occupied by them; at the same time, other two study sites (Bidrugodu and Anegundhe, Figure 5.2) were found uninhabited by these beetles towards the end of their adult active

season. Although we do not have any mark-recapture tests to provide a correct answer, we presume a high rate of dispersal or local migration among these tiger beetles (See map in the Figure 5.1 for the distance between study sites).

5.3.2 PREY PREFERENCE OF ADULT TIGER BEETLES

Both species started their activity during early monsoon (early July in 2003 and mid June in 2004), but maximum foraging activity was observed in mid July in both the years. Earthworms (Annelidae) and frog tadpoles (size 85 mm) (Ranidae: Anura) were identified as the very common prey for both species of tiger beetles until late August. Although they pursued other prey organisms like wolf spiders (Family Lycosidae) and ants during this period, both species were found attracted more to earthworms and tadpoles compared to other prey organisms. However, a marked disappearance of exposed earthworms and stranded tadpoles in drying small puddles and shallow ditches in paddy fields occurred late in the season. During this time the tiger beetles switched to more conventional prey organisms like ants and spiders (until early November). A detailed list of prey organisms observed eaten by tiger beetles in this study is given in Appendix III.

Except for *Polyrhachis exercita*, no significant difference in the mean capture rate of other prey organisms was found between *C. whithilli* and *C. flavomaculata*. *Cicindela whithilli* and *C. flavomaculata* were found to feed on an average of 6.3 and 4 individuals respectively of *P. exercita*, per hour (Kruskal-Wallis test, $H(1, N 16) = 5.957; P = 0.01$). The predation rate for the other frequently observed prey did not differ between tiger beetle species (Table 5.1).

Table 5.1 Mean capture rate (Range, number consumed within every one hour) of significant and key prey organisms by *C. whithilli* (CW) and *C. flavomaculata* (CF). Significance in the median capture rate between *C. whithilli* and *C. flavomaculata* is compared by Kruskal-Wallis rank ANOVA, N= number of beetles observed every one hour

Prey items	CW				CF			
	N	Range	Mean capture	±SD	N	Range	Mean capture	±SD
Tadpoles	10	7-15	11.4 ^A	2.63	7	7-14	11 ^A	2.31
Earthworm	5	2.5-4.5	4 ^A	1.04	5	2.5-5.5	4 ^A	2.29
<i>P. exercita</i>	10	3.5-8	6.3 ^A	1.78	6	2.5-5	4 ^B	4.11
<i>P. diversus</i>	10	7-13	10.2 ^A	1.93	5	6-12	9 ^A	4.07

Difference in characters shows significant difference in mean capture, $P = 0.01$

Table 5.2 Mean consumption time (Range in seconds) of significant prey organisms by *C. whithilli* (CW) and *C. flavomaculata* (CF). Significance in difference in the median consumption time compared by Mann – Whitney U test. N = Number of beetles observed every one hour time

Prey Item	CW				CF				U value
	N	Range	Mean	± SD	N	Range	Mean	± SD	
Tadpoles	7	20-36	27.28	5.88	5	40-60	52.2	9.18	0 (p=0.004)
Earthworms	5	252-720	511.2	193.61	5	510-870	690	173.64	6.5 (NS)

A comparison of mean consumption time by *C. whithilli* and *C. flavomaculata* showed that *C. whithilli* took relatively less time to consume preys like tadpoles and earthworms than *C. flavomaculata*. *C. whithilli* took 22 – 36 sec with an average of 27.28 sec to devour each tadpole, while *C. flavomaculata* took 40 – 60 sec with an average of 52.2 sec, and this difference in the mean consumption time between tiger beetle species was found significant (Mann-Whitney U test, $P= 0.004$). Although each puddle contained similar sized tadpoles, the size of earthworms in the study generally varied between 3.5 – 4.5 cm, but only worms of approximately 3.5 cm in length were analyzed. Although the mean consumption time for earthworms by *C. whithilli* (8.52 min) was shorter than *C. flavomaculata* (11.5 min) the difference was not significant (Table 5.2).

The species composition of ants in Areca and Acacia plantations is dissimilar from rice paddy fields, and it is reflected in the feeding differences of *C. duponti* (Appendix III). Primary food of *C. duponti* usually consists of several species of ants including *Paratrechina longicornis*, *Anoplolepis gracilipes* (Formicinae), *Cardiocondyla carbonaria* and *Tetramorium pacificum* (Myrmicinae). *Oecophylla smaragdina*, another common formicine ant in Acacia plantation, was an additional prey for *C. duponti*, but with a low rate of capture success, most likely because these ants are aggressive.

Several iterations of stop-and-go running were used by *C. whithilli* and *C. flavomaculata* to locate and capture mobile prey organisms like ants and spiders. Prey that moved by running followed by pause including ants (particularly noted in *Polyrhachis exercita*), wolf spiders (Lycosidae), and jumping spiders (Salticidae) alerted the tiger beetles. However, at least 40 percent of tiger beetles' attempts to capture Lycosid and Salticid spiders were unsuccessful when the prey became immobile even

though they were less than a centimeter away from the beetle. Generally, beetles were found touching their abdomen on wet ground while consuming food.

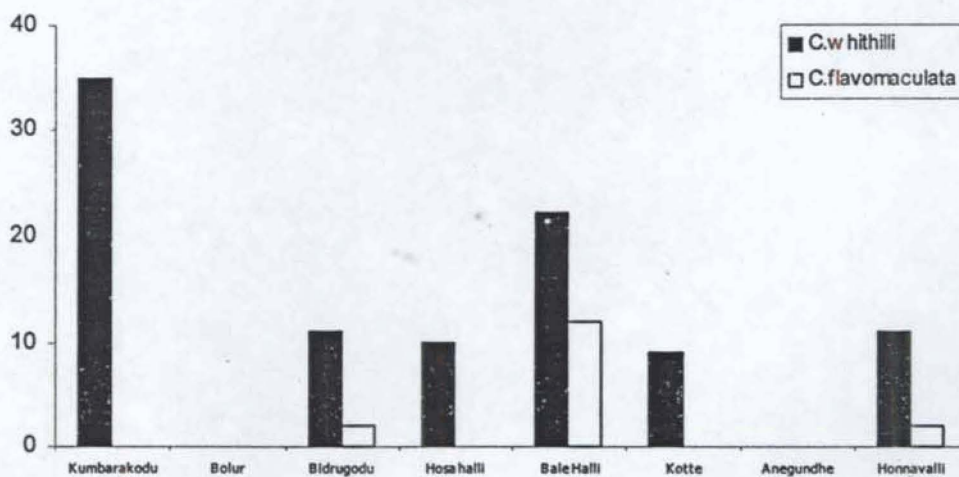
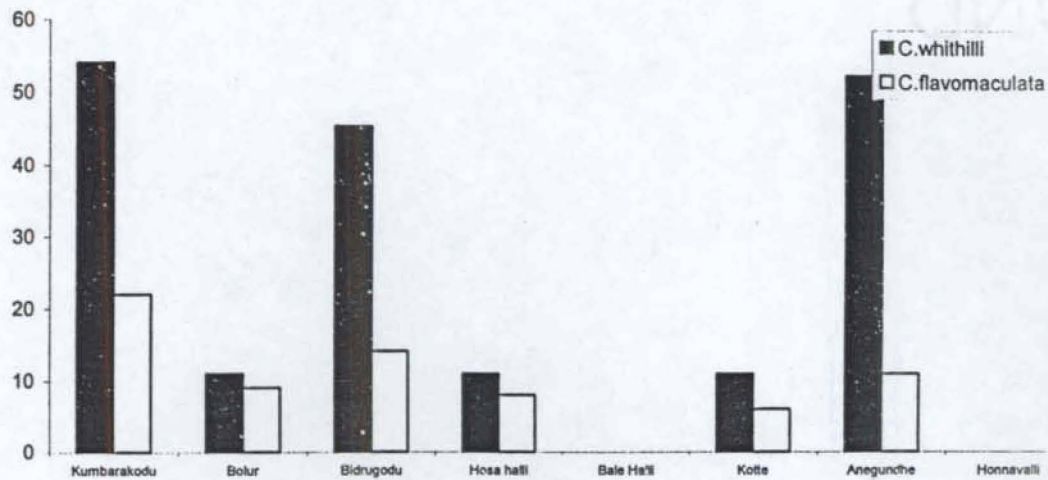


Figure 5.2. Abundance of *C. whithilli* and *C. flavomaculata* in the early and middle crop season paddy fields of Sringeri; upper panel, early crop season; lower panel, middle crop season

5.3.3 FORAGING STRATEGIES OF TIGER BEETLES ON EARTHWORMS AND TADPOLES

Although Pearson and Vogler (2001) reported that *Cicindela sedecimpunctata* in Arizona opportunistically take advantage of tadpoles as an atypical food resource under special circumstances, no studies are available on the predatory behavior of tiger beetles on

tadpoles. Indeed *C. whithilli* and *C. flavomaculata* may be the only two tiger beetle species that use tadpoles as a major food source, at least for a part of their adult stage (Table 5.1 & 5.2). Furthermore this appears to be the first report of earthworms as prey for tiger beetles. In the following paragraph we elaborate on the foraging strategies of tiger beetles on these unusual prey organisms.

A large number of tadpoles of species *Euphlyctis cyanophlyctis* (Schneider) were found in each of the small puddles that are formed during the rainy days in paddy fields. As the puddles dry out, they became shallower and the tadpoles became concentrated at the center of these pools. The tiger beetles then wait for the water to recede so that the tadpoles are buried in the remaining wet mud. During this time, the tiger beetles were found to probe the wet soil frequently with their mandibles and pull out the buried tadpoles to prey on them.

The capture rate of earthworms was high during rainy days as the earthworms exposed themselves on the substrate to escape inundation. Tiger beetles generally attacked the middle portion of the worm first to reduce the worm activity; this behavior, however, often allowed the worm to escape with half of its body.

5.3.4 Potential of tiger beetles in controlling major rice paddy pests

From our field surveys, none of these tiger beetles were found to feed extensively on any of the major paddy pests; although a limited range of predation on second nymphs (five out of twelve in laboratory tests) of *Leptocorisa acuta* by *C. whithilli* was observed. Meanwhile, other pests presented to captive tiger beetles went unnoticed by both tiger beetle species.

5.4 DISCUSSION

Emergence of all three tiger beetle species was observed immediately after the first few summer showers in May (81 mm of rain fall in 2003 & 190 mm in 2004). Hence, rainfall is likely to be the signal for termination of the pupal diapause of these beetles. Widespread emergence of all the three species occurred by the first few monsoon showers, which Sringeri received by 16th June in 2003 (rainfall in June, 758 mm) and 2nd June in 2004 (rainfall in June, 1017 mm). Both *C. whithilli* and *C. flavomaculata* occupy open rice paddy fields and bunds with sparse herb cover and moist soil. In contrast,

moderate shade by tall trees (in this study, Areca palms 9 – 12 yr old and *Acacia mangium* trees 7 yr old plantations) appears to be the most important habitat requirement for the occurrence of *C. duponti* in addition to sparse grassy bunds and sandy water channels. The decline in the number of *C. whithilli* and *C. flavomaculata* in all study sites and a simultaneous incidence of tiger beetles in previously uninhabited areas during the latter stage of their activity is most likely explained by a high rate of dispersal (Figure 5.2).

Cicindela duponti disappeared completely from all six study sites by mid October preceded by a well defined reproductive period between early August – mid October. The abundance of the other two species remained relatively constant into late December. However, notable change in their activities over the length of their adult activity season was observed. Individuals of *C. whithilli* and *C. flavomaculata* spent more than 60 percent of their time in finding a mate, and courting until late October in both the study years.

Although tiger beetles are defined as generalist hunters (but specific to relative size) of various live arthropods (Pearson and Mury, 1979, Pearson 1988) this may be the first report that earthworms are among typical prey organisms in their diet. We found that *C. whithilli* and *C. flavomaculata* prey more regularly on tadpoles and earthworms during early stages of their adult activity even though other conventional prey organisms like ants and spiders were abundant in their vicinity.

Adult tiger beetles are known for their active predation, which includes several iterations of 'stop and go running' before capturing the prey (Gilbert 1997). In other case, Kaulbars and Freitag (1993) have reported ambush predation of approaching prey by *Cicindela denikei* Brown. Tiger beetles in general are fluid feeders and use pre-oral digestion by the introduction of midgut enzymes (Evans 1965). However, feeding strategies of tiger beetles in the present study in capturing earthworms and tadpoles were slightly different from the conventional predatory behavior. Tiger beetles of both species were found to take less time to handle smaller preys than larger ones (Table 5.1). In another instance one *C. whithilli* was observed to eat termites (approximate size, 30 mm) at an average of 16 individuals per minute that were emerging from their ground nest.

Some tiger beetles also scavenge dead organisms and feed on non-typical food resources such as fruits (Pearson & Vogler 2001). It was found that both *C. whithilli* and *C. flavomaculata* scavenged on dead organisms including grubs of dung beetles (Scarabaeidae: Coleoptera), ground dwelling mole crickets (Gryllidae: Orthoptera) and adult *Cicindela whithilli* in field. Some non-typical prey organisms such as live *Clivina* sp. (Carabidae: Coleoptera) and ladybird beetles (Coccinellidae: Coleoptera) were preyed upon by *C. duponti* on certain occasions; it took almost 19 min to partly finish the heavily armed *Clivina* sp. and 15 min to completely feed upon the ladybird beetle.

The switching of adult tiger beetles' food resources from the 'tadpole-earthworm complex' in early season to various ants and spiders towards the latter foraging periods may be due to the availability of prey organisms as well as field conditions. In the early crop season, the ploughed paddy fields characteristically have loose soil and muddy pools, but they are not continuously water logged. The combination of these factors creates a suitable microclimate for the occurrence of tadpoles and earthworms as an additional food element in the beetles' prey type. During the latter period of the crop season the rice paddy fields were more solid and muddy and inhabited by ants and spiders.

The extensive feeding of *C. whithilli* and *C. flavomaculata* on tadpoles, ants and earthworms (classified as ecologically important organisms), which was observed in the present study, do suggest that these two species of tiger beetles may have a negative impact on the ecosystem structure.

Although *C. whithilli* and *C. flavomaculata* share their habitat, food resources and microclimate, tug-of-wars between individuals were observed frequently while feeding on earthworms. The frequent touching of the rear portion of the abdomen of tiger beetles, while feeding, can be explained as a thermoregulatory action by which beetles can efficiently transfer the excess body heat to the wet ground (Dreisig 1980).

Robber flies (Asilidae: Diptera), dragonflies (Libellulidae: Odonata) and water scorpions (Nepidae: Heteroptera: Insecta) were observed to be natural enemies of *C. whithilli* and *C. flavomaculata*. Unlike robber flies and dragonflies that are aerial predators, water scorpions were found ambushing tiger beetles that were hunting for

Should have been recorded in the results

tadpoles and earthworms in the muddy substratum, and this is the first report of an aquatic insect as a predator of adult tiger beetles.

The results of our preliminary laboratory experiments show minimal predatory potential of *C. whithilli* and *C. flavomaculata* on major rice paddy pests in Sringeri during the study period. Only observations of their occasional capture of nymphs of *L. acuta* indicate some small potential as biocontrols. *Leptocorisa acuta* is a serious pest in South and Southeast Asian countries.

The present study proposes two reasons for which *C. whithilli* and *C. flavomaculata* are unlikely to be efficient natural enemies of other major rice paddy pests (except *L. acuta*) in Sringeri: (1) the beetles are ground dwellers and restrict their feeding to wet muddy substratum in rice paddy fields, and are not active climbers (either for roosting or feeding). [However, during periods of flooding, beetles aggregate on plants. In one instance more than 300 individuals of *C. whithilli* were found roosting on rice paddy saplings (age, 48 days after transplantation) for 4 days without any activity until the water receded (See plate)], and (2) the other possible and accessible prey organisms such as brown plant hopper (*Nilaparvata lugens*) and Yellow stem borers (*Scirpophaga incertulus*) that usually attack the root level of rice paddy saplings were not available in Sringeri region during the study period in 2003 and 2004. However, a study by Sastry and Appanna (1958) found that *Cicindela flavomaculata* feeds on rice stem borers (Lepidoptera: Pyralidae), a major rice paddy pest in irrigated paddy fields of south Indian plains, and few of other researchers (Shivashankar and Kumar, unpublished data) and Veeresh (pers. Comm.) have illustrated the positive economic importance of *C. flavomaculata* over some other paddy pests.

5.4.1 CONCLUSIONS

Our study thus contributes to a better understanding of the feeding guild of tiger beetles, which includes arthropods and vertebrates. It also give an insight on the bio control potential of tiger beetles that neither *C. whithilli* nor *C. flavomaculata* meet the criteria to be significant natural enemies of rice paddy pests at least in Sringeri area. However, our experimental findings are based on relatively short-term data and more research is needed before tiger beetles can be excluded as beneficial natural enemies.

What about the
Practical Mohanraj?

Chapter 6

SUMMARY AND CONCLUDING REMARKS

In this Chapter, a brief summary of the key findings of this research, and farmer's changing attitude on rice paddy cultivation in Sringeri area is analyzed.

6.1 SUMMARY OF THE THESIS

1. The one-year field survey brought out 34,242 individuals of terrestrial arthropods, which belong to 814 species from 179 families, and 18 orders of insects and spiders. Seasonal turn over between fallow and crop season paddy fields was very high on arthropod community of paddy fields, especially on aerial arthropods. If fallow paddy lands attracted more generalist species, which were also found in other adjacent land use corridor habitat types, cultivated paddy field was occupied by highly specialized arthropods like pest groups, and natural enemy guilds. The population build up of both pests and natural enemy groups were more seasonal, and were totally dependant on the age of the rice paddy saplings. Nevertheless, not a single economically important major pest, apart from *L. acuta*, was recorded from Sringeri area. However, the study recommends the need to monitor *Nymphula depunctalis* and *N. fluctosalis*' behavioral responses to the changing climate conditions. Although these two defoliator species were not important

pests of rice paddy saplings, the study points out their potential to become major pests of upland rice paddy fields, at least for *Malnada* region of the Western Ghats in near future. As the larvae and pupae were always found inside the cases made of the paddy leaf blades, pesticides may be ineffective in reducing the population structure of these two species. Increasingly, both the species were found to pupate mostly under water in the field, which restrict the number of potential natural enemies of these two pest species in the wild. The high rainfall and successive water current in the field help the pest to infest rice paddy saplings in a vast area in a short stretch of time. However, identification of an ichneumonid pupal parasitoid, *Litochila sp.* parasitizing *N. depunctalis* and their behavioral modifications, to search for the hidden defoliator pupae, even beneath the water surface, leave a ray of hope in natural biological control of this pest. Behavioral modification of rice paddy pests between seasons also is possible. The change in the feeding habit of *Euproctis sp.* from rice paddy leaves in the Kharif season to rice paddy flowers in the Rabi season, had a high economic importance in the ~~coming~~ season.

subsequent

2. Parasitic hymenopterans and jumping and orb weaving spiders were the predominant natural enemies of a good proportion of rice paddy pests, and other herbivores. Considerable difference in the species richness as well as dominance in the specialized parasitoids was found between fallow and crop seasons. While, wasps of two species of Braconidae were the widely encountered natural enemies of rice paddy fields of age 30 DAT. However, *Litochila sp.* was the abundant beneficial natural enemy during nursery and early sapling stages of rice paddy fields. *Scenocharops sinui* was the dominant ichneumonid parasitoid in the 30 DAT rice paddy fields, which was highly correlated to the *C. medinalis* pest abundance in the field. Spiders were the highly polyphagous predators of rice paddy lands throughout the study period. Seasonal changes were observed in the occurrence of spiders too. *Tetragnatha sp.* was the only abundant, and widely observed orb-weaving spider of the cultivated rice paddy lands of Sringeri. Increasingly, the web of *Tetragnatha sp.*, which normally locates parallel to the water surface, was always found trapped with numerous Chironomid flies, which

is a minor pest of rice paddy saplings. However, *Oxyopes javanus* was the active and potential predator of a number of paddy pests, including adults of *Nymphula spp.*, and *C. medinalis*. Furthermore, a good number of other beneficial natural enemies, particularly Coenagrionid damsel flies, and Ichneumonid wasps of various species, were also found eaten by this spider species very often in the field. Spider population, apart from these two species, and a water spider, *Pisaurus sp.* were relatively less abundant in the irrigated ~~cultivated~~ paddy fields. Interestingly, though tiger beetles of two species, *Cicindela whitthilli* and *C. flavomaculata* were seen in large numbers in paddy fields, with the onset of cultivation, and their numbers remained high till the end of cultivation practice, their role as beneficial natural enemies of paddy pests were minimal or absent. The feeding guild of these two beetles comprised of a wide range of other beneficial fauna of paddy lands, such as spiders, ants, beetles, tadpoles of frogs, and earthworms. The study, therefore showed that tiger beetles of these two species were rather injurious than beneficial to the well-being of the rice paddy lands of Sringeri.

3. Although rice paddy fields are considered as an intensive monoculture agro-ecosystem, a ~~good number~~ ^{rich} of flora was also seen in the paddy field proper in the fallow period, and on the bunds throughout year. A total of 125 weed species were enumerated on the paddy bunds during cultivation period. However, as most of these species appeared as the wild relatives of rice paddy plants, synchronization in the flowering and fruiting occurs between rice paddy and other weed species. This was a very crucial factor for the incidence of *L. acuta* in the rice paddy fields; *L. acuta* was spotted ² in the flora of bunds, and nearby Areca Orchards well before rice paddy flowering started. Two weed species *Cyperus rotundus*, and *Fimbristylis dichotoma* flowered massively before the rice paddy flowering took place in the field, which attracted these bugs into the field. Meanwhile, a good number of Asteracean species also flowered during the cultivation period, which in adjacent uncultivated lands formed a floral carpet, and attracted both lepidopteran pests, and adult natural enemies like parasitic wasps.

4. The study demonstrated that arthropod community of rice paddy agro – ecosystems to be an entirely different entity, and showed a minimal species similarity with other adjacent land use corridor habitat types. Ground arthropod community of fallow lands, relative to aerial arthropod community, had shown more similarity to the adjacent uncultivated land use types. Nevertheless, the very actively flying insects, as captured ⁱⁿ on Malaise traps, had shown a considerable species similarity between paddy lands and other land use corridors. However, arthropods trapped in the Malaise traps during fallow period appeared as vagrants, and were not paddy specialists. Among ground arthropod community, ground dwelling spiders would be the largest group, which ^{were} ~~are~~ found roaming around fallow grounds and other adjacent land use types; a remarkable spider community similarity between corridor habitats, and fallow lands ^{was} ~~were~~ observed in the study. Representatives of three species of wolf spiders (Family: Lycosidae) and one species of Oxyopidae (*Oxyopes* (sp 2)) appeared as habitat generalists, and were found to occur in all adjacent land use habitats along with paddy fields. Although, Carabid beetles ^{were} ~~are~~ generally believed to be the other polyphagous predator group, the community similarity between heterogeneous land use types and paddy fields was relatively low. Incidentally, during crop season, aerial arthropods, particularly parasitic hymenopteran movement from adjacent land use corridor habitats to the rice paddy crop lands was remarkably high, and points ^{ed} to the importance of maintaining heterogeneous habitats, adjacent to farm lands. Although, Areca orchard is generally believed as a man made monoculture habitat type at macro vegetation level, a wide range of wild herbaceous, and grass species were found to invade the orchard ground, due to relatively open canopy and nutrient rich soil. This understory flora heterogeneity of (AR) orchard appeared to have a positive impact on the parasitic hymenopteran diversity too. Interestingly, in another study (Sinu 2003), parasitic hymenopteran diversity at all levels appeared to be high in (AR) orchard, ^{when} compared to natural forest and other three habitat types of Sringeri.

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5. Although the impact of stand simplification in the adjacent land use types was not significant for arthropod diversity of the paddy fields, ground and aerial arthropod diversity of the fallow lands adjacent to heterogeneous *Soppinabetta* forests was high, and Acacia plantation adjacent to fallows appeared to have the lowest diversity. Areca orchard – paddy agro – landscape was ranked second in terms of arthropod diversity. The flora of paddy field proper was most diverse in the Areca related fallow lands, and the one adjacent to Acacia plantation had the lowest diversity. Meanwhile, the variation in floral diversity of the paddy bunds during the cultivation period was similar to that of the arthropod community, *Soppinabetta* adjacent paddy fields had more floral diversity, and Acacia plantation near paddy field had least floral diversity. Meanwhile, arthropod diversity of the *Soppinabetta* corridor habitat was relatively high, as compared to monoculture habitat types, Degraded Scrub forest ranked first on arthropod diversity, but the difference was only due to 9 species, between Degraded Scrub and *Soppinabetta* forest. Whereas lower strata floral richness was high in the *Soppinabetta*, and was least in the Acacia plantation. The study therefore illustrates the importance of maintaining habitat heterogeneity in the agro – landscape in order to preserve arthropod biodiversity, and particularly for the beneficial arthropod community required for the farmlands.
6. Arthropod diversity, particularly diversity of major functional groups, such as pests and natural enemy guilds of farmlands ^{were} are determined, jointly by within and surrounding habitat floral diversity, and several other environmental parameters. In this study, it was found that the response of arthropod community of paddy lands to habitat and environmental variables was taxa or species specific. The stand richness and abundance of the fallow land proper and paddy bunds, rather than corridor habitat floral diversity primarily determined fallow ground and aerial arthropod community. However, it appeared that the flora diversity, specifically, flora richness of paddy bunds was significantly and positively linked to the spider diversity, rather than any other functional guilds. Apart from the paddy bund flora diversity, fallow proper vegetation density seemed to have a significant positive impact on the spider and other ground arthropod diversity.

The impact of surrounding corridor habitat stand diversity on arthropod diversity of rice paddy lands was weak, and sometime had a negative impact too. Surprisingly, no selected environmental variables, other than soil humidity had a significant impact in determining arthropod diversity of rice paddy lands of Sringeri. At the same time, the impact of soil variables like Organic Carbon content or phosphate level on arthropod diversity was either nil, or significantly negative; whereas, these were the significant positive correlates of the fallow vegetation. However, the impact of distance gradient on arthropod diversity as well as grain productivity was marginal. The impact of distance gradient from the corridor – paddy interface, on aerial arthropod diversity was not similar between fallow and crop period. If paddy fields adjacent to corridors were more diverse in terms of abundance of arthropods during fallow period, aerial arthropods, particularly parasitoids, and a pest species, *Cnaphalocrocis medinalis* were increasing, when moving away from the paddy edges in the cultivated paddy lands. The findings therefore partially agree with both *natural enemy* and *resource concentration hypotheses*. Meanwhile, no substantial difference in productivity, as estimated by the count of grains per ear hill, with distance from field edges, was observed.

6.2 CHANGING SCENARIO OF RICE PADDY CULTIVATION AND THREATS TO THE RICE PADDY LANDS OF SRINGERI

Major threat to rice paddy lands of Sringeri area of Malnad region is massive land conversion to other horticultural crops. Conversion to Areca orchards and Acacia plantations were the only threat to the rice paddy lands till a year back in Sringeri. However, nowadays a good proportion of rice paddy lands are being converted into Ginger plantations, due to its high market value. However, farmers claim that the paddy conversion to Ginger cultivation is only a temporary arrangement, and they would be cultivating rice paddy every alternate year. Meanwhile, the conversion to Areca orchards and Acacia plantations poses a threat, and the impact would be massive and irreversible too, which even leads to the extinction of this wetland ecosystem of this upland region.

Although, farmers get a moderate to high yield, which normally varies between 900 – 1800 kg / Acre, with an average of 1300 Kg/Acre, most of the farmers are looking forward to convert the lands into other crop and plantation varieties. Steep fall in the rate of rice, and a drastic increase in the rate of other short-term crops like ginger, were the main reason behind the change in the mindset of these farmers. The unsteady climate conditions also lead the farmers to move away from cultivating rice paddy in Sringeri. It would be worth here to mention that, nearly 60 % of the farmers of Sringeri had lost the rice paddy seedlings due to the heavy rain and flood, which lashed Sringeri and Agumbe region in ^{the} this year (2005), which resulted in at least 4 of the farmers stop ^{the} cultivating rice paddy this year. 12

Most of the farmers mainly depend upon organic compost to improve soil fertility of rice paddy fields of Sringeri, and they primarily depend on *Soppinabetta* forests, and to a small extent, also access adjacent reserve forests, to collect leaf litter and green foliages, towards the organic subsistence. Increasingly, most of these private forests are being overexploited to meet the increasing demand for the organic compost for the Areca orchards. As against the rotational leaf litter harvesting, almost all the *Soppinabetta* forests are being intensively harvested, which nowadays vary from one to two times a year. Furthermore, now, more than 80 % of small, medium, and large-scale farmers are being compelled to buy organic compost from 'illegal dealers', who harvest leaf litter and green foliages throughout the year, from their own *Soppinabetta* forests and also from the neighbouring ones, and also exploit reserve forests too, which normally cost Rs. 15 / butti (1 butti = 30 Kg.) to farmers. 13

After a preliminary analysis, it was observed that the conversion of nearly 0.50 % of *Thari* (rice paddy cultivation) lands to *Bhagayath* (Horticultural crops) has taken place in a three-year period between 2001 and 2004, and 0.08 % of increase in the *Bhagayath* lands ^{was} were accounted during the same period. However, the data presented here ^{was} is only a preliminary one obtained from Farmers Association of Sringeri. A more detailed survey data from Municipality authorities for past ten years ^{is} is needed, to measure the magnitude of the threat to this unique marshy agro – ecosystem.

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* Original not seen

Appendix 1

Arthropods collected from various treatments of Sringeri rice paddy agro - landscape

Order	Family	Species	Crop Season					Off Season					Total	
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy		
Araneae	Araneidae	<i>Araneus sp 1</i>										1	1	
		<i>Cyrtarachne sp 1</i>										1	2	
	Coriniidae	<i>Castianeira zetes</i>					2			1	1	4	8	
		<i>Castianeira sp 1</i>									4	5	9	
		<i>Oedignatha sp 1</i>							4	8			12	
	Ctenidae	<i>Cterus sp 1</i>								1	1	3	5	
	Gnaphosidae	<i>Dassodes sp 1</i>											2	2
		<i>Gnaphosa sp 1</i>										1	2	3
		<i>Poecilochora sp 1</i>									1		3	4
		<i>Poecilochora sp 2</i>									2		1	3
		<i>Scotophaeus sp 1</i>					1	2					5	8
		<i>Zeloies sp 1</i>										4	4	
	Linyphiidae	<i>Erigone sp 1</i>						1	1			5	7	
		<i>Erigone sp 2</i>						3	1	6		2	12	
		<i>Erigone sp 3</i>					2			1		6	9	
	Lycosidae	<i>Hippasa sp 1</i>						2				1	3	6
		<i>Lycosa sp 1</i>					3	25	6	26	15	444	519	
		<i>Pardosa pseudoannulata</i>							2	2		69	73	
		<i>Pardosa sumatrana</i>						1	6	6	3	99	115	
	Oonopidae	<i>sp 16a</i>					3	1	2	3	4	13		
	Oxyopidae	<i>Oxyopes sp 1</i>					1						1	
		<i>Oxyopes sp 2</i>					5		32	50	1	14	102	
	Pisauridae	<i>Dolomedes sp 1</i>										2	2	
	Platoridae	<i>sp 24a</i>										1	1	
	Salticidae	<i>Bavia sp 1</i>										3	3	
		<i>Bianor sp 1</i>							3	1		6	10	
		<i>Bianor sp 2</i>										3	3	
		<i>Bianor sp 3</i>					1						1	
		<i>Brettus sp 1</i>										1	1	
		<i>Corhottus sp. 1</i>								1			1	
		<i>Hasarius sp 1</i>										1	1	
		<i>Hyllus sp 1</i>				1						3	4	
		<i>Myrmerachne plataleoides</i>							1					1
		<i>Myrmerachne sp 1</i>							3	1	2	3	9	
		<i>Phintella vittata</i>									2	1	3	

authored for
Scientific Name?

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		<i>Rhene flavigera</i>	1					4	6	1	58		70
		<i>Rhene sp 1</i>						1					1
		<i>sp 28a</i>									1		1
		<i>sp 31a</i>									3		3
		<i>sp 3a</i>									2		2
		<i>Telamonia dimidiata</i>								1			1
	spider	<i>sp 12a</i>									2	1	3
		<i>sp 13a</i>					5	3	3	3	1		15
		<i>sp 14a</i>							1				1
		<i>sp 22a</i>							1				1
		<i>sp 26a</i>							1				1
		<i>sp 27a</i>									1		1
		<i>sp 38a</i>						1	1				2
		<i>sp 43a</i>					3	2	2	2	1		11
		<i>sp 4a</i>					2				1		3
		<i>sp 55a</i>			1	1							2
		<i>sp 6a</i>						1	1		2		4
	Tetragnathidae	<i>Tetragnatha sp 1</i>				2	49						51
	Theridiidae	<i>Argyrodes sp 1</i>				3		10	1	1			15
	Thomisidae	<i>Camaricus formosus</i>							2				2
		<i>Misumena sp 1</i>						1	1		2		4
		<i>Runcinia sp 1</i>						1		1	5		7
		<i>sp 34a</i>							1				1
		<i>Strigoplus netravati</i>							1				1
		<i>Thomisus lobosus</i>				1					1	2	4
Blattaria	Blatellidae	<i>sp 2a</i>		2		1		9	4	4	24		44
	Blattidae	<i>sp 1a</i>						5	12	6	19	5	47
		<i>sp 3a</i>				1					3		4
Coleoptera	Anthicidae	<i>sp 122a</i>									1		1
		<i>sp 155a</i>			1					1	2		4
		<i>sp 179a</i>				1					3		4
		<i>sp 186a</i>	1					1					2
		<i>sp 245a</i>				1							1
		<i>sp 43a</i>	2			1		2		22	1	282	310
		<i>sp 9a</i>									1		1
	Anthribidae	<i>sp 195a</i>								1	1		2
		<i>sp 197a</i>									3		3
		<i>sp 198a</i>									5		5

Order	Family	Species	Crop Season					Off Season					Total						
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy							
		<i>sp 30a</i>										3			1	4			
		<i>sp 31a</i>													1	1			
		<i>sp 32a</i>													27	33			
		<i>sp 34a</i>											3		15	18			
		<i>sp 35a</i>													17	17			
		<i>sp 37a</i>										2			166	168			
		<i>sp 44a</i>										2	1	1	1	3	8		
		<i>sp 49a</i>													6	7			
		<i>sp 51a</i>													1	19	20		
		<i>sp 55a</i>										4	3	82	4	466	559		
		<i>sp 62a</i>													1	3	4		
		<i>sp 73a</i>														1	9	10	
		<i>sp 76a</i>													1	1	2		
		<i>sp 83a</i>													1	6	7		
		<i>sp 88a</i>														1	1		
	Cerambycidae	<i>sp 218a</i>													1		1		
		<i>sp 233a</i>														1	1		
	Chrysomelidae	<i>sp 108a</i>	1												1		2		
		<i>sp 12a</i>													2	8	1	102	113
		<i>sp 136a</i>	1													3		4	
		<i>sp 138a</i>														4		19	
		<i>sp 154a</i>										1	1	1				3	
		<i>sp 156a</i>													1			1	
		<i>sp 160a</i>													4			4	
		<i>sp 167a</i>													4			5	
		<i>sp 169a</i>														2	2	4	
		<i>sp 173a</i>													1			1	
		<i>sp 178a</i>													1			1	
		<i>sp 181a</i>													1			1	
		<i>sp 189a</i>															5	5	
		<i>sp 193a</i>														9	3	13	
		<i>sp 200a</i>																2	
		<i>sp 204a</i>														1	1	2	
		<i>sp 205a</i>															1	1	
		<i>sp 206a</i>															1	1	
		<i>sp 209a</i>														1		1	
		<i>sp 210a</i>														1		1	
		<i>sp 213a</i>															2	2	

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		<i>sp 219a</i>										1	1
		<i>sp 223a</i>											1
		<i>sp 242a</i>											2
		<i>sp 249a</i>				1							1
		<i>sp 257a</i>										1	1
		<i>sp 40a</i>						1				1	5
		<i>sp 59a</i>										3	3
		<i>sp 82a</i>									3		3
		<i>sp 86a</i>						1			2	2	5
		<i>sp 87a</i>								5		1	6
		<i>sp 92a</i>								1			1
	Cicindelidae	<i>sp 217a</i>						1					1
		<i>sp 243a</i>											2
		<i>sp 244a</i>											1
	Cleridae	<i>sp 115a</i>										1	1
		<i>sp 165a</i>									1		1
		<i>sp 166a</i>										36	36
		<i>sp 174a</i>								1		1	2
		<i>sp 214a</i>								1			1
		<i>sp 216a</i>									1		1
		<i>sp 26a</i>					1			1		93	95
		<i>sp 53a</i>					4					69	84
	Coccinellidae	<i>sp 187a</i>		1				2		7	1	1	2
		<i>sp 38a</i>							1		2	8	11
		<i>sp 39a</i>										20	20
	Corylophidae	<i>sp 112a</i>								1			1
	Cucujidae	<i>sp 104a</i>									1		1
		<i>sp 106a</i>										1	1
		<i>sp 111a</i>								1			1
		<i>sp 175a</i>										1	1
		<i>sp 183a</i>						3		3	2		8
		<i>sp 238a</i>					1						1
		<i>sp 250a</i>				1							1
	Curculionidae	<i>sp 123a</i>							1				1
		<i>sp 148a</i>									1		1
		<i>sp 190a</i>						2			1		3
		<i>sp 194a</i>								9	8		48
		<i>sp 201a</i>								1			1

Order	Family	Species	Crop Season					Off Season					Total		
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy			
		<i>sp 227a</i>													1
		<i>sp 229a</i>													1
		<i>sp 231a</i>													1
		<i>sp 235a</i>													1
		<i>sp 248a</i>				1									1
		<i>sp 41a</i>				1	2			3				2	8
		<i>sp 65a</i>								1	2	1		5	9
		<i>sp 68a</i>												5	5
		<i>sp 78a</i>												19	19
	Dytiscidae	<i>sp 135a</i>										1			1
	Elateridae	<i>sp 171a</i>								1	1				2
		<i>sp 177a</i>												1	1
		<i>sp 199a</i>										1			1
		<i>sp 225a</i>				2						1			2
		<i>sp 234a</i>					1	1							2
		<i>sp 241a</i>						1							1
		<i>sp 252a</i>					1								1
		<i>sp 52a</i>									2			31	33
		<i>sp 55a</i>												5	5
		<i>sp 77a</i>						1			4			30	35
		<i>sp 84a</i>												5	5
	Eucnemidae	<i>sp 8a</i>				1					3			16	20
		<i>sp 170a</i>									1				1
		<i>sp 184a</i>								1					1
	Heteroceridae	<i>sp 246a</i>					1								1
	Histeridae	<i>sp 5a</i>												8	8
		<i>sp 91a</i>												2	2
	Hydrophilidae	<i>sp 114a</i>												1	1
	Laemophloeidae	<i>sp 72a</i>								9	34	7	13	26	89
	Languriidae	<i>sp 96a</i>								3				4	7
	Leiodidae	<i>sp 107a</i>											2		2
	Meloidae	<i>sp 203a</i>												1	1
	Melolonthidae	<i>sp 42a</i>								16	62	14	7	5	104
	Melyridae	<i>sp 258a</i>									4				4
	Mordellidae	<i>sp 94a</i>											1		2
	Nitidulidae	<i>sp 113a</i>				1							1	4	5
		<i>sp 134a</i>												1	2
		<i>sp 139a</i>												1	1

Order	Family	Species	Crop Season					Off Season					Total	
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy		
		<i>sp 195a</i>	5				2			6				13
	Paussidae	<i>sp 75a</i>							1	2	2			5
		<i>sp 100a</i>										1		1
	Phalacridae	<i>sp 159a</i>										1		1
		<i>sp 17a</i>	1	2	1	1	6					11		22
	Pselaphidae	<i>sp 66a</i>										19		19
		<i>sp 130a</i>									1			1
		<i>sp 253a</i>					1							1
	Ptiliidae	<i>sp 93a</i>			1		4	1			1	2		9
		<i>sp 102a</i>									2			2
		<i>sp 147a</i>		1			6				1			8
	Rhipiphoridae	<i>sp 222a</i>		1			2							3
	Rhynchitidae	<i>sp 126a</i>									9			9
	Scarabaeidae	<i>sp 215a</i>									1			1
		<i>sp 103a</i>										1		1
		<i>sp 10a</i>								10	1	5		16
		<i>sp 11a</i>										24		24
		<i>sp 127a</i>									1			1
		<i>sp 132a</i>										3		3
		<i>sp 141a</i>												1
		<i>sp 142a</i>								1				1
		<i>sp 14a</i>								2	1			3
		<i>sp 151a</i>										148		148
		<i>sp 152a</i>										1		1
		<i>sp 157a</i>								1				1
		<i>sp 20a</i>								1		1		2
		<i>sp 23a</i>								2		60		62
		<i>sp 256a</i>						2				7		9
		<i>sp 25a</i>										1		1
		<i>sp 28a</i>										8		8
		<i>sp 28a</i>							1	2	1	4		8
		<i>sp 29a</i>										4		4
		<i>sp 2a</i>										133		133
		<i>sp 33a</i>						6	10	37	3	42		98
		<i>sp 36a</i>										4		4
		<i>sp 3a</i>								53		159		212
		<i>sp 46a</i>										6		6
		<i>sp 47a</i>										4		4
		<i>sp 48a</i>								2		16		18

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		<i>sp 4a</i>						2		3	1	41	47
		<i>sp 50a</i>										1	1
		<i>sp 54a</i>								3		1	4
		<i>sp 58a</i>								1	1	6	8
		<i>sp 63a</i>									7	70	77
		<i>sp 64a</i>							2	26	35		63
		<i>sp 6a</i>										1	1
		<i>sp 70a</i>								1	10	4	15
		<i>sp 74a</i>								17	11	5	33
		<i>sp 7a</i>								1		8	9
		<i>sp 95a</i>						1					1
	Scirtidae	<i>sp 168a</i>										1	1
	Scolytidae	<i>sp 61a</i>					1		5	1	1	17	25
		<i>sp 89a</i>						1	1	1	1		3
	Staphylinidae	<i>sp 101a</i>									2	1	3
		<i>sp 105a</i>			1			3			3	1	8
		<i>sp 109a</i>								3			3
		<i>sp 110a</i>								2			2
		<i>sp 128a</i>									1		1
		<i>sp 129a</i>							1		2		4
		<i>sp 13a</i>		1					4	1	6	177	188
		<i>sp 149a</i>					1					1	2
		<i>sp 158a</i>										1	1
		<i>sp 180a</i>							1				1
		<i>sp 18a</i>						1	1		1	1	4
		<i>sp 19a</i>						1				16	17
		<i>sp 21a</i>							5	4	1	16	26
		<i>sp 228a</i>					1						1
		<i>sp 239a</i>					1						3
		<i>sp 240a</i>					2						4
		<i>sp 24a</i>										2	2
		<i>sp 45a</i>							1	1		1	3
		<i>sp 57a</i>										3	3
		<i>sp 60a</i>							1			1	2
		<i>sp 67a</i>								1	3	5	9
		<i>sp 69a</i>				2			1				3
		<i>sp 71a</i>										1	1
		<i>sp 76a</i>							1				1

Order	Family	Species	Crop Season					Off Season					Total		
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy			
		sp 89a													7
		sp 90a													1
	Luxaniidae	sp 99a				1									1
	Micropezidae	sp 106a		1											1
	Muscidae	sp 112a												1	1
		sp 20a			5								1		6
		sp 34a							2						2
		sp 35a			1	1	65	2	8	2	31	267			377
		sp 36a					2	2				1			5
		sp 38a					2				1	2			5
		sp 52a					121	3	8	2		52			186
		sp 55a					1								1
		sp 57a					1								1
		sp 58a					1	2							3
		sp 5a			1		69	4	4	3	1	21			103
		sp 62a	2				4	1							7
		sp 63a					8								8
		sp 66a					46		3			31			80
		sp 92a					1								1
	Mycetophilidae	sp 50a	1	13	4		10								28
		sp 56a		2	2	5	9					2			20
		sp 98a					3								3
	Neurochaetidae	sp 18a					3					1			4
	Otitidae	sp 115a							1						1
	Phoridae	sp 11a	2	35	2	23	166	17	9	8	45	36			343
		sp 6a		13			7		6	2	1	13			42
		sp 87a		3											3
	Pipunculidae	sp 105a					1								1
		sp 176a					2								2
		sp 41a											1		1
	Psychodidae	sp 64a		43		5	14					1			63
	Sarcophagidae	sp 21a					13			2		4			19
		sp 2a					3	2				21			26
	Scathophagidae	sp 19a										1			1
	Scatopsidae	sp 17a										1			1
		sp 71a					1								1
	Sciaridae	sp 114a								1		2			3
		sp 147a					12								12

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		<i>sp 1a</i>	12	91	30	55	198	9	13	2	2	65	477
		<i>sp 3a</i>					2					2	4
		<i>sp 47a</i>					7					1	8
	Sepsidae	<i>sp 13a</i>					1				2	6	9
		<i>sp 59a</i>					1						1
		<i>sp 7a</i>						3					3
	Simulidae	<i>sp 88a</i>					1						1
	Sphaeroceridae	<i>sp 10a</i>		6		2	13		4	2		24	51
		<i>sp 29a</i>							8				8
		<i>sp 4a</i>		5			13		5	1		25	49
		<i>sp 85a</i>		11			1						12
	Syrphidae	<i>sp 101a</i>		1									1
		<i>sp 16a</i>								1		1	2
		<i>sp 51a</i>					1						1
		<i>sp 77a</i>					1						1
		<i>sp 93a</i>					2					2	4
		<i>sp 97a</i>		1			1						2
	Tabanidae	<i>sp 40a</i>		1			13			1			15
		<i>sp 54a</i>				1	11	7	1			10	30
		<i>sp 9a</i>			1		32	10	4		11	90	148
	Tachinidae	<i>sp 43a</i>					2					4	6
	Tephritidae	<i>sp 25a</i>							1			1	2
		<i>sp 27a</i>							1			6	7
		<i>sp 44a</i>									1		1
	Tipulidae	<i>sp 68a</i>	2	3		4	47						56
		<i>sp 81a</i>		1		1	12	1					15
Ephemeroptera	Caenidae	<i>sp 1a</i>					17						17
Heteroptera	Anthocoridae	<i>sp 23a</i>							2		1	24	27
		<i>sp 29a</i>					2	1					3
	Aradidae	<i>sp 1a</i>							1			13	14
		<i>sp 34a</i>					1						1
	Coreidae	<i>sp 17a</i>							2	1	1	2	6
		<i>sp 26a</i>							5			1	6
		<i>sp 27a</i>						3		4			7
		<i>sp 30a</i>				1	29						30
	Dipsocoridae	<i>sp 33a</i>		2	1		2						5
	Gerridae	<i>sp 11a</i>									1		1
	Lygaeidae	<i>sp 16a</i>								2	11	3	16

Order	Family	Species	Crop Season					Off Season					Total		
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy			
		sp 19a									1			1	
		sp 20a								1			1	2	
		sp 2a								3	43			277	326
		sp 3a								2	5			10	17
		sp 6a								3	3	15	24	53	98
		sp 9a											1	4	5
	Miridae	sp 10a								1				4	5
		sp 12a												3	3
		sp 24a								1	3	4			9
		sp 28a								8					8
	Pentatomidae	sp 15a												1	1
		sp 31a													1
		sp 5a									10	4	2	137	153
	Reduviidae	sp 13a										2		1	3
		sp 14a												2	2
		sp 18a	1											1	2
		sp 21a									1				1
		sp 25a											1		1
		sp 4a												9	9
		sp 7a									1	3		6	10
		sp 8a										1		1	3
	Thyrecoridae	sp 22a										5		22	27
	Tingidae	sp 32a													1
	Cercopidae	sp 27a													1
	Cicadellidae	?Scaphotettix sp.				1							4	3	8
		Aconurella sp.												217	225
		Balclutha incisa (Matsumura)	2											1	6
		Chiasmus uzeli Melichar									1	2		183	186
		Deltocephalus (Recilia) dorsalis			1		1	137							139
		Deltocephalus sp.			1			10	2	9	1			106	129
		Dussana sp.							1						1
		Empcascanara sp.			10		5	31		2	1			57	106
		Exitianus indicus (Distant)	1						2	6	3			84	96
		Hecalus apicalis (Matsumura)						1		8		1		14	24
		Hecalus sp.												18	18
		Idioscopus decoratus Viraktamath											2		2
		Mimotettix sp.							1	1			4		6
		Nephotettix virescens (Distant)	1				5	221							231
			183		4		5	221							

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		<i>Orosius albicinctus</i> Distant										21	21
		<i>Pen'himia</i> sp.										2	2
		<i>Platyretus</i> sp.		1			1						2
		<i>Stirellus</i> sp.										1	1
		<i>Tettigoniella iocosta</i> Distant								1		3	4
		<i>Ujna ? Delicatula</i> Distant		1									1
		<i>Xestocephalus</i> sp.										2	2
	Cixiidae	<i>Oliarus</i> sp.				1	18		1			3	23
	Delphacidae	<i>Sogatella furcifera</i> (Horvath)				1	119						120
		sp 2a						2		1		8	11
		sp 6a		1			4		3			50	58
	Dictyopharidae	sp 21a										1	1
	Flatidae	sp 1a				1				1	1	1	4
	Issidae	sp 16a										1	1
	Membracidae	sp 17a								1			1
	Psyllidae	sp 31a				1							1
Hymenoptera	Anthophoridae	sp 233a					1						1
	Aphelinidae	sp 173a					4						4
		sp 183a					1						1
	Apidae	sp 236a					1						1
		sp 27a							2	4		8	14
	Bethylidae	sp 224a				1							1
		sp 29a		1					1	2	1	26	31
		sp 53a				2		6	3		1	12	24
	Braconidae	<i>Aleiodes (Aleodes)</i> sp.				1	11					1	13
		<i>Apanteles</i> sp 1		3		2	91		1		1	4	102
		<i>Aspidobracon</i> sp.					40						40
		<i>Chelonus</i> sp 1					3						3
		<i>Choeras</i> sp 1					1						1
		<i>Opius</i> sp 1		1			46				1		48
		<i>Opius</i> sp 2					3	2	3		2	5	15
		<i>Phanerotoma</i> sp 1								1			1
		<i>Praon</i> sp 1										1	1
		sp 243a										1	1
		sp 48a				2		1			3		6
	Ceraphronidae	sp 133a		1		1	11		1				14
		sp 188a					1						1
		sp 60a										1	1

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		<i>sp 63a</i>	1	2	1		14		1			5	24
		<i>sp 84a</i>							1				1
	Chalcididae	<i>Brachymeria ascarinata</i>					2					2	4
		<i>Brachymeria bengalensis</i>					1						1
		<i>Brachymeria lasus</i>			1		17						18
		<i>Dirhinus anthracia</i>										1	1
		<i>Hockeria sp 1</i>							1		1	2	4
		<i>Hockeria sp 2</i>										2	2
	Chrysididae	<i>sp 162a</i>					2		1			2	5
		<i>sp 247a</i>										1	1
	Diapriidae	<i>Entomacis spinosus</i>					1						1
		<i>sp 69a</i>					3	5	2		2	1	13
		<i>Trichopria fringa</i>		1			1						20
	Dryinidae	<i>sp 177a</i>					1						1
	Elasmidae	<i>sp 128a</i>					1				1		35
	Encyrtidae	<i>Agarwalencyrtus sp 1</i>							1			1	2
		<i>Dolichoceras sp 1</i>		2			1						7
		<i>Encyrtus sp 1</i>										1	1
		<i>Leptomastidea sp 1</i>		1									1
		<i>Metaphycus sp 1</i>					1					1	2
		<i>Paratetracnemoidea sp 1</i>										1	1
		<i>sp 203a</i>					1						1
		<i>sp 222a</i>			1								1
		<i>sp 52a</i>					1					26	27
	Eucharitidae	<i>Schizaspidia sp 1</i>					1					1	2
	Eucoilidae	<i>sp 111a</i>		1			5	1			1	1	9
		<i>sp 231a</i>		1									1
	Eulophidae	<i>Aprostocetus sp 1</i>		2			19						21
		<i>Aprostocetus sp 2</i>					1						11
		<i>Aprostocetus sp 3</i>	1		2		4					6	13
		<i>Aprostocetus sp 4</i>	1		1	1	4		1			3	11
		<i>Aprostocetus sp 5</i>										1	1
		<i>Asecodes sp 1</i>										2	2
		<i>Diglyphomorphomyia sringeriensis</i>							1				1
		<i>Elachertus sp 1</i>		1			3						4
		<i>Euderus sp 1</i>										1	1
		<i>Litus sp 1</i>										1	1
		<i>Neomestocharella sp 1</i>					3						3

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		<i>Notanisomorphella sp 1</i>	3			1	2					4	10
		<i>Parahorismenus femorata</i>					1						1
		<i>Parasecodella bouceki</i>								1	4		5
		<i>Parasecodella sp 1</i>									3		3
		<i>Quadrastichus sp 1</i>								1			1
		<i>Quadrastichus sp 2</i>					1						1
		<i>sp 167a</i>					4						4
		<i>sp 169a</i>					3						3
		<i>sp 215a</i>		3									3
		<i>sp 232a</i>					1						1
		<i>sp 237a</i>					1				1		2
		<i>sp 239a</i>							1		1		2
	Eupelmidae	<i>Tetrastichus mangifera</i>	1				50		1		1		53
		<i>Callipteroma sexgutatta</i>					1				1		2
		<i>Neanastatus turneri</i>							2				2
		<i>sp 155a</i>		1	1								2
	Eurytomidae	<i>Euplectrus dubeyi</i>					2						2
		<i>Eurytoma agalica</i>									1		1
		<i>Eurytoma dentata</i>									1		1
		<i>Eurytoma setitibia</i>									3		3
		<i>Eurytoma sp 1</i>									3		3
		<i>sp 229a</i>		1									1
	Evaniidae	<i>sp 208a</i>		1				1			4	1	7
		<i>sp 248a</i>						1					1
	Formicidae	<i>sp 100a</i>							3	1	1	1	6
		<i>sp 105a</i>									2		2
		<i>sp 106a</i>									2		2
		<i>sp 10a</i>										1	1
		<i>sp 110a</i>										1	1
		<i>sp 114a</i>									1		1
		<i>sp 117a</i>						1	5		5	1	12
		<i>sp 120a</i>										1	1
		<i>sp 121a</i>						1					1
		<i>sp 122a</i>										1	1
		<i>sp 124a</i>								1			1
		<i>sp 125a</i>									1		1
		<i>sp 12a</i>					1	9	2	6	31	57	106
		<i>sp 13a</i>					5	13		25	2	43	88

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		sp 146a										2	2
		sp 148a								1			1
		sp 14a							1	1	3	15	20
		sp 15a						8	61	67	62	233	431
		sp 16a										12	12
		sp 17a								2		23	25
		sp 18a							1	5	2	60	68
		sp 19a								1	2		3
		sp 1a			3	2	3	78	26	29	22	507	670
		sp 20a								12	9	2	23
		sp 22a			2				50	20	8	15	95
		sp 23a		1				15	38	5	19	2	80
		sp 24a					1	10	14	40	8	204	277
		sp 25a					1			2		2	5
		sp 26a				11				26	4	5	46
		sp 28a						3		3		107	113
		sp 2a			2		6	43	23	87	38	507	706
		sp 31a							5	21	13	40	79
		sp 32a										1	1
		sp 33a										1	1
		sp 34a										7	7
		sp 35a						4		14	3	8	29
		sp 36a					1		3	14	12	2	32
		sp 3a		2	8		33	1961	662	469	52	1548	4735
		sp 41a						1	5	4	2	7	19
		sp 42a							1	50	4	31	86
		sp 44a					1	1	4	8	3	22	39
		sp 45a								1		1	2
		sp 46a						1		4	2	22	29
		sp 47a								1	1		2
		sp 49a									1		1
		sp 4a			6		4	268	234	36		1283	3536
		sp 50a									70	5	75
		sp 54a			2			1	228		2	409	642
		sp 56a						1		9	7	10	27
		sp 57a							79	11		14	104
		sp 58a								9	2	1	12
		sp 59a								49	2		51

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		sp 5a						6	1	7		41	55
		sp 66a							1			8	9
		sp 6a						137	306	45	34	244	766
		sp 70a							1			1	2
		sp 71a				1				1			2
		sp 74a							1				1
		sp 75a							7				7
		sp 76a							30			4	34
		sp 7a					2	14	1			107	124
		sp 81a							2	1			3
		sp 82a							6			62	68
		sp 83a						1		32		4	37
		sp 86a								17	1		18
		sp 87a						3		29	2	20	54
		sp 88a						1				12	13
		sp 89a						1		28	422	6	457
		sp 8a							1			1	2
		sp 90a										3	3
		sp 94a									1		1
		sp 95a		1		2			1	122	20	14	160
		sp 96a									8		8
		sp 97a									1		1
		sp 99a								1			1
		sp 9a										12	12
	Halictidae	sp 101a								1		6	7
		sp 113a					1			1		8	10
		sp 118a						4				7	11
		sp 196a					1						1
		sp 55a					2		1	2		3	8
	Ichneumonidae	<i>Mesochorus</i> sp.		2		1	2						5
		<i>Oriotohemeteles</i> sp.									1		1
		<i>Paraphylax</i> sp.					1						1
		<i>Scenocharops</i> sp.					10						10
		sp 185a					2						2
		sp 201a				1	1						2
		sp 225a					2						2
		sp 227a					1						1
		sp 223a					1						1

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		<i>sp 249a</i>						1					1
		<i>Termetucha sp</i>								1	1		2
	Mutillidae	<i>Xanthopimpla punctata</i>					10						10
		<i>sp 140a</i>									1		1
		<i>sp 21a</i>						2	1		4		7
		<i>sp 30a</i>							2		31		33
		<i>sp 37a</i>									9		9
		<i>sp 93a</i>									1	1	2
	Mymaridae	<i>Anagrus sp 1</i>				1	14	1	1		7		24
		<i>Anagrus sp 2</i>					1						1
		<i>Gonatocerus sp 1</i>		4	1	1	117	3	2		9	34	171
		<i>sp 108a</i>		3		1					1		5
		<i>sp 209a</i>		1									1
	Ormyridae	<i>sp 136a</i>										3	3
	Platygasteridae	<i>sp 11a</i>								2	1	45	48
		<i>sp 149a</i>		9		1	42	1	1		3		57
		<i>sp 161a</i>					7						7
	Pompilidae	<i>sp 197a</i>					1						1
		<i>sp 235a</i>					1						1
		<i>sp 240a</i>										1	1
		<i>sp 38a</i>						5			2		7
	Pteromalidae	<i>Narendrella nilamburensis Sureshan</i>		1			4				1		6
		<i>Panstenon sp 1</i>					2						2
		<i>Pteromalus sp 1</i>					1						1
	Scelionidae	<i>sp 103a</i>										1	1
		<i>sp 132a</i>				2			2			1	5
		<i>sp 143a</i>		1			19	1	1			11	33
		<i>sp 145a</i>										1	1
		<i>sp 160a</i>		5	4		48		1				58
		<i>sp 164a</i>	2	1			41						44
		<i>sp 176a</i>		2		1	6						9
		<i>sp 191a</i>					2						2
		<i>sp 192a</i>		1	1		39						41
		<i>sp 195a</i>		3	3	2	11						19
		<i>sp 206a</i>		1			2						3
		<i>sp 230a</i>		1									1
		<i>sp 238a</i>										1	1
		<i>sp 241a</i>										10	10

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		<i>sp 242a</i>										1	1
		<i>sp 246a</i>								2			2
		<i>sp 40a</i>							1			4	5
		<i>sp 61a</i>									2	2	4
		<i>sp 64a</i>										4	6
		<i>sp 65a</i>									1	1	2
		<i>sp 72a</i>										3	3
		<i>sp 77a</i>										2	4
		<i>sp 78a</i>			1			1				1	3
		<i>sp 80a</i>									1	5	6
		<i>sp 92a</i>							2		1	9	12
	Scoliidae	<i>sp 189a</i>		2								1	5
		<i>sp 190a</i>		3						7			10
	Signiphoridae	<i>sp 187a</i>											7
	Sphecidae	<i>sp 104a</i>		1						2		1	10
		<i>sp 115a</i>										1	1
		<i>sp 116a</i>			1			2				4	9
		<i>sp 119a</i>										1	1
		<i>sp 123a</i>										2	2
		<i>sp 127a</i>						3	1			1	5
		<i>sp 200a</i>											1
		<i>sp 204a</i>											1
		<i>sp 210a</i>		1									1
		<i>sp 225a</i>											1
		<i>sp 244a</i>										1	1
		<i>sp 245a</i>										5	5
		<i>sp 39a</i>										1	1
		<i>sp 85a</i>										1	1
	Tiphiidae	<i>sp 142a</i>						1				1	2
	Trichogrammatidae	<i>sp 163a</i>										4	46
		<i>sp 166a</i>	1	4									30
		<i>sp 180a</i>											1
		<i>sp 194a</i>										2	3
	Vespidae	<i>sp 234a</i>										1	2
Lepidoptera	caterpillar 3	<i>sp 3a</i>										1	2
	Caterpillar4	<i>sp 4a</i>										1	1
	hairy caterpillar	<i>sp 2a</i>						4	5	1	2	1	13
	Hesperiidae	<i>Borbo cinnara</i>											7

Order	Family	Species	Crop Season					Off Season					Total	
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy		
		<i>Parnara mathias</i>		1		3	8							12
		<i>sp 10a</i>			1		1							2
		<i>Taractrocera ceramas</i>					3							3
	moth12	<i>sp 12a</i>		1			1							2
	moth13	<i>sp 13a</i>		1										1
	moth14	<i>sp 14a</i>		2			2							4
	moth15	<i>sp 15a</i>		4	1		2							7
	moth16	<i>sp 16a</i>		1		2								3
	moth17	<i>sp 17a</i>		1										1
	moth18	<i>sp 18a</i>					1							1
	Noctuidae	<i>Spodoptera litura</i>	1	1			4							6
		<i>Spodoptera mauritia</i>					15							15
	Nymphalidae	<i>Melanitis leda</i>					52							52
		<i>Mycalæsis perseus</i>			1		1							2
		<i>Orsotrioena medus</i>					2							2
		<i>sp 6a</i>	1	2		7	7							17
	Papilionidae	<i>sp 19a</i>					1							1
	Pieridae	<i>Nymphula fluctosalis</i>					5							5
		<i>sp 5a</i>	1											1
		<i>sp 9a</i>			1		1							2
	Pyralidae	<i>Cnaphalocrocis medinalis</i>		2		1	129							132
		<i>Scirpcphaga incertulus</i>	1	2			1							4
		<i>sp 11a</i>					1							1
		<i>sp 1a</i>							2		1	41		44
		<i>sp 8a</i>					1							1
Mantoidea	Mantidae	<i>sp 1a</i>				1					3	2		6
Neuroptera	Myrmeliontidae	<i>sp 1a</i>								1	1	3		5
Odonata	Coenagrionidae	<i>sp 1a</i>					19							19
		<i>sp 2a</i>				1	9							10
		<i>sp 3a</i>					5							5
		<i>sp 4a</i>					4							4
Orthoptera	Acrididae	<i>sp 11a</i>							1	3		1		5
		<i>sp 15a</i>							1	1		2		4
		<i>sp 16a</i>							1			1		2
		<i>sp 5a</i>					17	2	14	2	2	99		136
		<i>sp 6a</i>						1	17	1	1	72		92
		<i>sp 8a</i>										1		1
	Gryllidae	<i>sp 10a</i>							1	2		1		4

Order	Family	Species	Crop Season					Off Season					Total
			AC	AR	DS	SB	Paddy	AC	AR	DS	SB	Paddy	
		<i>sp 14a</i>					1	2	5	2	4	5	19
		<i>sp 17a</i>							1				1
		<i>sp 1a</i>				1		18	17	9	12	219	276
		<i>sp 3a</i>		1				6	2	2	7	39	57
		<i>sp 9a</i>						2			3	32	37
	Gryllotalpidae	<i>sp 20a</i>										3	3
	Pyrgomorphidae	<i>sp 18a</i>										11	11
		<i>sp 21a</i>						2		1		63	66
	Tetrigidae	<i>sp 12a</i>									1	13	14
		<i>sp 13a</i>		1		1	2		6		2	19	31
		<i>sp 2a</i>					1		7		2	42	52
		<i>sp 7a</i>								3		6	9
	Tridactylidae	<i>sp 4a</i>			1							19	20
Psocoptera	Psocidae	<i>sp 1a</i>						2	3	1	1	3	10
		<i>sp 2a</i>										3	3
Thysanoptera	Phlaeothripidae	<i>sp 1a</i>	9	4	4	14	1333	1	21	1	1	23	1411
		<i>sp 2a</i>		1			11	1	2		2	1	18
		<i>sp 3a</i>							1			1	2
Thysanura	Lepismatidae	<i>sp 1a</i>									13	33	46
Count of species in each treatment			33	108	48	91	294	127	198	222	212	451	814

Appendix II

Flora of Sringeri rice paddy agro – landscape: fallow proper, paddy bund, and lower strata flora of adjacent corridor habitats

Family	Species	Crop season					Off season
		SB	DS	AR	AC	Bund	Fallows
Acanthaceae	<i>Asystasia cristata</i>	*		*	*	*	
	<i>Justicia simplex</i>	*	*	*	*	*	
	<i>Phaulopsis imbricata</i>			*	*	*	
	<i>Rungia</i> sps	*					*
	<i>Staurogyne zeylanica</i>	*	*	*	*	*	
	<i>Tarena bicolor</i>	*				*	
Amarathaceae	<i>Cyathula prostrata</i>			*			
Amarillidaceae	<i>Curculigo orchoides</i>	*				*	
Apiaceae	<i>Centella asiatica</i>	*	*	*	*	*	
	<i>Hydrocotyle asiatica</i>						*
Apocynaceae	<i>Ichnocarpus frutescens</i>	*		*	*		
Araceae	<i>Colocasia esculenta</i>			*			
	<i>Colocasia</i> sps	*		*			
Arecaceae	<i>Areca catachu</i>			*			
	<i>Caryota urens</i>			*			
Asteraceae	<i>Ageratum conyzoides</i>	*	*	*	*	*	*
	<i>Bidens</i> sps			*	*		
	<i>Blumea barbata</i>					*	
	<i>Blumea oxydonta</i>		*	*		*	
	<i>Blumea</i> sps					*	*
	<i>Blumea</i> sps					*	
	<i>Centranth. ereum anthelmenicum</i> ?					*	
	<i>Chromolaena odorata</i>	*	*	*	*	*	*
	<i>Eclipta alba</i>		*			*	*
	<i>Elephantopus scaber</i>	*	*	*			
<i>Emilia sonchifolia</i>	*		*		*		
<i>Grangea maderaspatana</i>			*		*	*	

What are
SB
DS
AR
AC

What are "sps" ?
Could there be spp. ?

Family	Species	Crop season					Off season Fallows
		SB	DS	AR	AC	Bund	
	<i>Gynura nitida</i>			*		*	
	<i>Helianthus annuus</i>			*			
	<i>Spilanthes ciliata</i>					*	
	<i>Spilanthes sp.</i>						*
	<i>Synedrella nodiflora</i>			*			
	<i>Vernonia cinerea</i>					*	
	<i>Vicoa indica</i>					*	
Balsaminaceae	<i>Impatiens chinensis</i>	*	*	*	*	*	
	<i>Impatiens diversifolia</i>				*	*	
Boraginaceae	<i>Heliotropium indicum</i>						*
Brassicaceae	<i>Parthenium sps</i>					*	
Burmanniaceae	<i>Burmania caelestis</i>						*
Caesalpianaceae	<i>Cassia tora</i>	*	*			*	*
Combretaceae	<i>Combretum sps</i>	*					
Commelinaceae	<i>Commelina clavata</i>		*				
	<i>Commelina diffusa</i>		*				
	<i>Commelina sps</i>					*	
	<i>Cyanotis cristata</i>	*	*			*	
	<i>Murdannia nudiflora</i>	*		*	*	*	
	<i>Murdannia spirata</i>					*	
Convolvulaceae	<i>Argyreia sps</i>	*					
	<i>Ipomoea paniculata</i>			*	*		
	<i>Ipomoea sps</i>	*					
	<i>Merremia turpethum</i>	*	*	*			
Crassulaceae	<i>Bryophyllum pinnatum</i>	*					
Cyperaceae	<i>Bulbostylis barbata</i>					*	
	<i>Cyperus corymbosus</i>					*	
	<i>Cyperus dichotoma</i>					*	
	<i>Cyperus difformis</i>					*	
	<i>Cyperus iria</i>	*	*			*	

Family	Species	Crop season					Off season
		SB	DS	AR	AC	Bund	Fallows
	<i>Cyperus nutans</i>					*	
	<i>Cyperus rotundus</i>	*		*		*	*
	<i>Cyperus sps</i>	*				*	*
	<i>Cyperus tomentosus</i>					*	
	<i>Cyperus triceps</i>		*			*	
	<i>Fimbristylis argentia</i>	*				*	
	<i>Fimbristylis dichotoma</i>		*			*	
	<i>Fimbristylis falcata</i>					*	
	<i>Fimbristylis pentantra</i>					*	
	<i>Fimbristylis sps</i>	*	*			*	*
	<i>Fimbristylis sps4</i>						*
	<i>Fimbristylis sps5</i>						*
	<i>Fimbristylis tomentosus</i>	*		*		*	*
	<i>Mariscus sps</i>					*	
	<i>Pycnus flavidus</i>					*	
	<i>Pycnus macrostachyos</i>			*		*	
	<i>Pycnus pumilus</i>		*			*	*
	<i>Pycnus sp</i>						*
	<i>Schoenoplectus mucronatus</i>	*				*	
	<i>Schoenoplectus sps</i>		*			*	*
Dioscoriaceae	<i>Dioscoria bulbifera</i>	*					
	<i>Drocaera burmanii</i>					*	
Dipterocarpaceae	<i>Hopea ponga</i>	*					
Drocaeraceae	<i>Drocaera burmanii</i>						*
Elatinaceae	<i>Bergia ammanoides</i>						*
Eriocaulaceae	<i>Eriocaulon sps</i>	*	*		*	*	*
Euphorbiaceae	<i>Phyllanthus amara</i>					*	*
	<i>Phyllanthus sps</i>	*		*		*	*
	<i>Phyllanthus sps</i>						*
	<i>Phyllanthus sps-1</i>						*

Family	Species	Crop season					Off season Fallows
		SB	DS	AR	AC	Bund	
Fabaceae	<i>Alisicarpus hamosus</i>	*		*		*	
	<i>Crotalaria retusa</i>	*	*				
	<i>Crotalaria sps</i>						*
	<i>Desmodium sps</i>	*		*		*	
	<i>Desmodium trifolium</i>	*	*			*	*
	<i>Geisepis cristata</i>	*	*	*		*	
	<i>Tephrosia purpurea</i>						*
	<i>Vinga sps</i>	*	*				
Family 1	<i>canscora/exacum yellow flower</i>						*
Family 2	<i>Caryophyllacean/glinus</i>						*
Family 3	<i>Fern</i>			*			
Family 4	<i>Lobelia yellow</i>						*
Gentianaceae	<i>Canscora sps</i>	*				*	
	<i>Hopea dichotoma</i>					*	*
Gesneriaceae	<i>Gesneriaceae sp 1</i>						*
Gesneriaceae	<i>Exacum sps</i>					*	
Lamiaceae	<i>Colebrookea sps</i>	*				*	
	<i>Leucas aspera</i>	*		*	*	*	*
	<i>Leucas sps</i>	*	*			*	
	<i>Pogostemon sps</i>						*
Leeaceae	<i>Leea indica</i>	*		*	*		
Lobeliaceae	<i>Lobelia alsinoides</i>	*	*	*			
Lytheraceae	<i>Ammania buccifera</i>						*
	<i>Ammania sps</i>						*
	<i>Rotala macrandra</i>			*		*	*
Malvaceae	<i>Abutilon sps</i>					*	
	<i>Sida acuta</i>	*				*	
	<i>Sida rhombifolia</i>	*		*		*	
	<i>Sida sps</i>	*				*	
	<i>Sida sps1</i>		*				

Family	Species	Crop season					Off season
		SB	DS	AR	AC	Bund	Fallows
Melastomataceae	<i>Cyclea peltata</i>		*				
	<i>Melastoma malabathricum</i>	*			*		
	<i>Osbeckia octandra?</i>	*					
	<i>Osbeckia truncata</i>		*			*	
Mimosaceae	<i>Mimosa pudica</i>	*	*	*	*	*	*
Molluginaceae	<i>Glinus oppositifolius</i>						*
Myrsinaceae	<i>Maesa indica</i>	*					
Myrtaceae	<i>Syzygium caryophyllatum</i>	*					
Najadaceae	<i>Luzula compestris</i>					*	
Oleaceae	<i>Jasminum malabaricum</i>			*			
Onagraceae	<i>Ludwigia octovalvis</i>						*
	<i>Ludwigia perennis</i>			*		*	*
Orchidaceae	<i>Habenaria sps</i>		*				
Oxalidaceae	<i>Oxalis corniculata</i>			*		*	
Piperaceae	<i>Piper nigrum</i>	*					
Poaceae	<i>Apocopsis courtalensis</i>	*	*		*	*	
	<i>Arthraxon lanceolatum</i>					*	
	<i>Arundinella sps</i>	*	*		*	*	
	<i>Axonopus affinis</i>	*	*			*	
	<i>Axonopus compressus</i>	*	*	*	*	*	*
	<i>Axonopus sps</i>						*
	<i>Chrysopogon sps</i>					*	
	<i>Cirtococum sps</i>	*		*	*	*	*
	<i>Cynodon dactylon</i>	*		*		*	*
	<i>Dactyloctenium aegypticum</i>					*	
	<i>Digitaria bicornis</i>	*	*			*	
	<i>Digitaria sps</i>		*	*		*	
	<i>Digitaria sps-1 see book</i>						*
	<i>Dimaria ornithopoda</i>	*	*			*	*
	<i>Elusine indica</i>	*	*			*	

Family	Species	Crop season					Off season Fallows
		SB	DS	AR	AC	Bund	
	<i>Eragrostis sps</i>		*			*	
	<i>Eragrostis uniloides</i>	*	*			*	*
	<i>Eriochloa procera</i>		*	*		*	
	<i>Heteropogon contortus</i>					*	
	<i>Isachnae miliacea</i>	*	*		*	*	*
	<i>Jansenella griffithiana</i>				*	*	
	<i>Leersia hexandra</i>		*		*	*	
	<i>Oplismenus sps</i>	*	*				
	<i>Oriza sativa</i>					*	*
	<i>Paspalum sps</i>						*
	<i>Pennisetum pedicellatum</i>					*	
	<i>Poa sp 1</i>		*	*	*	*	
	<i>Sacciolepis indica</i>	*	*	*		*	*
	<i>Setaria sps</i>	*	*			*	
	<i>Setaria sps</i>					*	
	<i>Sporobolus diander</i>		*		*	*	
	<i>Sporobolus sps</i>		*			*	
	<i>Themeda triandra</i>	*			*	*	
Polygalaceae	<i>Polygala sps</i>	*	*		*		*
Polygonaceae	<i>Polygonum chinense</i>			*	*		
Ponderidaceae	<i>Monochoria sps</i>					*	
Rubiaceae	<i>Hedyotis biflora?</i>						*
	<i>Hedyotis corymbosa</i>						*
	<i>Hedyotis diffusa</i>					*	
	<i>Hedyotis herbaceae</i>	*	*			*	
	<i>Hedyotis nitida</i>	*					
	<i>Hedyotis sps</i>					*	*
	<i>Ixora coccinea</i>	*					
	<i>Spermacoce hispida</i>	*	*	*	*	*	
	<i>Spermacoce mauritiana</i>	*	*	*	*	*	*

Family	Species:	Crop season					Off season
		SB	DS	AR	AC	Bund	Fallows
	<i>Spermacoce</i> <i>sps</i>	*	*	*	*	*	
	<i>Spermacoce</i> <i>sps</i>						*
Rununculaceae	<i>Naravelia zeylanica</i>	*					
Sapindaceae	<i>Cardiospermum helicacabum</i>			*			
Sapotaceae	<i>Madhuca longifolia</i>	*					
Scrophulariaceae	<i>Limnophila chinensis</i>		*			*	
	<i>Limnophila heterophylla</i>						*
	<i>Limnophila repens</i>					*	
	<i>Limnophila</i> <i>sps</i>		*			*	
	<i>Lindernia antipoda</i>		*			*	*
	<i>Lindernia crustacea</i>	*	*			*	*
	<i>Lindernia hissypioides</i>					*	*
	<i>Lindernia oppositifolia</i>		*			*	
	<i>Lindernia parviflora</i>						*
	<i>Lindernia pusilla</i>					*	*
	<i>Microcarpaea minima</i>						*
	<i>Ramphicarpa longiflora</i>					*	
	<i>Scoparia dulcis</i>	*		*		*	
	Scrophulariaceae sp1						*
	<i>Striga</i> <i>sps</i>					*	*
	White flower with yello throat						*
See previous descriptions	<i>canscora/exacum</i> yellow flower						*
Selaginellaceae	<i>Selaginella</i> <i>sps</i>	*		*		*	
Solanaceae	<i>Capsicum frutescens</i>			*			
	<i>Solanum</i> <i>sps</i>						*
Tiliaceae	<i>Triumfetta</i> <i>sps</i>	*	*		*	*	
Urticaceae	<i>Laportea interrupta</i>			*			
	<i>Pouzolzia pentandra</i>					*	
Verbenaceae	<i>Clerodendron viscosum</i>	*		*			
	<i>Vitex negundo</i>		*			*	

What is *sps* should it be *sp*?

Family	Species	Crop season					Off season Fallows
		SB	DS	AR	AC	Bund	
Vitaceae	<i>Vitis bicolor</i>			*			
Xyridaceae	<i>Xyris india</i>		*				
Zingiberaceae	<i>Curcuma sp</i>	*	*	*	*		

authentic
Curcuma sp
Vitis bicolor

Appendix III Feeding guilds of tiger beetles

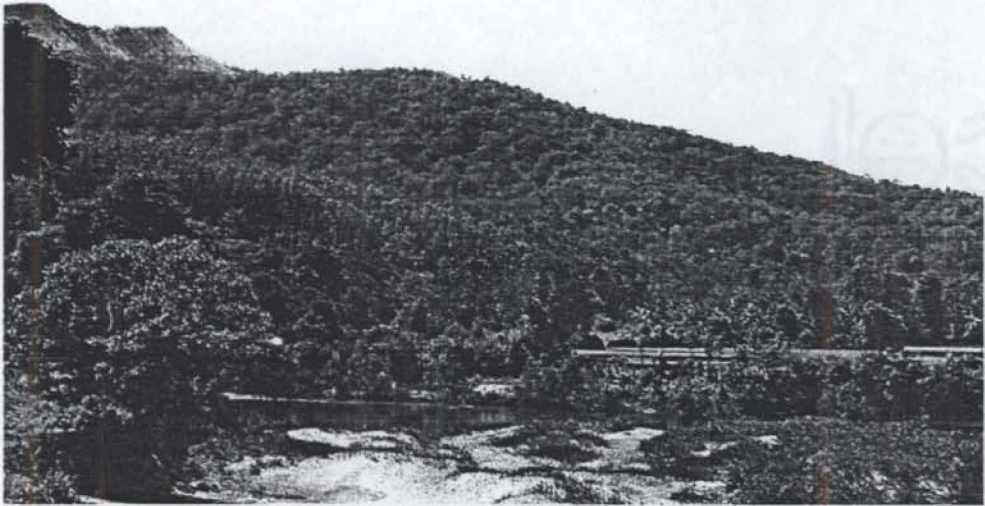
Class	Order	Family	Species	CW	CF	CD
Oligochaeta	Opisthoptera		Earthworms	*	*	
Amphibia	Anura	Ranidae	Tadpoles of <i>Euphlyctis cyanophlyctis</i> (*	*	
Arachnida	Araneae	Salticidae	<i>Bavia</i> sp	*	*	
			<i>Bianor</i> sp 1	*	*	
			<i>Bianor</i> sp 2	*		
		Lycosidae	<i>Pardosa sumptuosa</i> <i>la</i>	*		
			<i>Pardosa pseudoannulata</i>	*		
		Gnaphosidae	<i>Zelotus</i> sp.	*		
Insecta	Hymenoptera	Formicidae	<i>Polyrachis exercita</i>	*	*	
			<i>Polyrachis hauxwelli</i>	*	*	
			<i>Camponotus angusticollis</i>	*		
			<i>Pheidolegeton diversus</i>	*	*	
			<i>Pachycondyla tesseronoda</i>	*		
			<i>Paratrechina longicornis</i>			*
			<i>Cardiocondyla carbonaria</i>			*
			<i>Tetramorium pacificum</i>			*
			<i>Anoplolepis gracilipes</i>			*
			<i>Oecophylla smaragdina</i>			*
			<i>Tetraoponera allaborans</i>			X
			<i>Camponotus parvus</i>			X
			<i>Diacamma rugosum</i>	X		
	Diptera	Ephydriidae	<i>Ochthera</i> sp.	*		
	Coleoptera	Coccinellidae	sp 1	*		
		Carabidae	<i>Clivina</i> sp.	*		
		Dytiscidae	sub adults	*		
		Scarabaeidae	grub	o	o	
		Cicindelidae	<i>Cicindela whitthilli</i>	o		
	Isoptera	Termitidae	sp 1	*	*	
	Orthoptera	Gryllidae	sp 1	o	o	
	Heteroptera	Coreidae	<i>Leptocoris</i> <i>acuta</i>	*	*	

* Preferred prey, * fighters, ° carcasses

with the same names!

Ochtheridae Hemiptera?

Plate 1



a. A wider landscape of Sringeri showing all major habitats: Reserve forests, Soppinabetta forests, Acacia plantations, Areca orchards, Degraded Scrub, Rice paddy lands, and river Tunga



b. Changing land use pattern: A close up view of Sringeri landscape

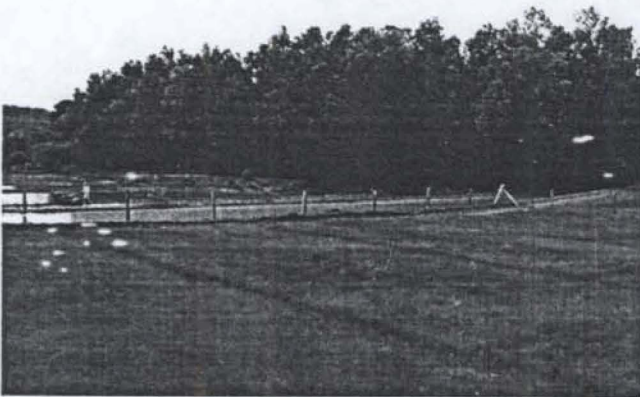
Colour photos would have been better



a. Paddy fields adjacent to Soppinabetta, SB Paddy



b. Paddy field adjacent to Degraded Scrub, DS Paddy



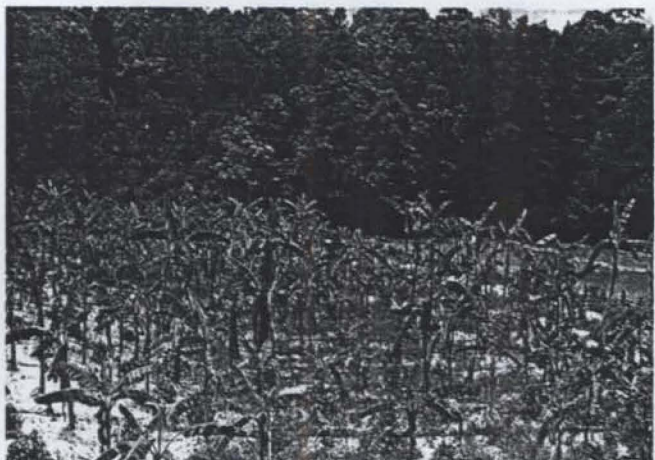
c. Paddy field adjacent to Acacia auriculiformis, AC Paddy



d. Paddy field adjacent to Areca Orchard AR Paddy



e. Paddy field is converted into Acacia plantation

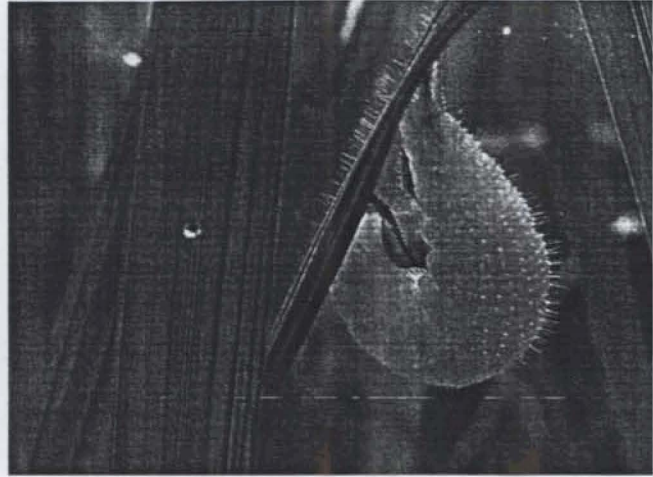


f. A one year old Areca orchard in the transformed Paddy field (in one of my study site)

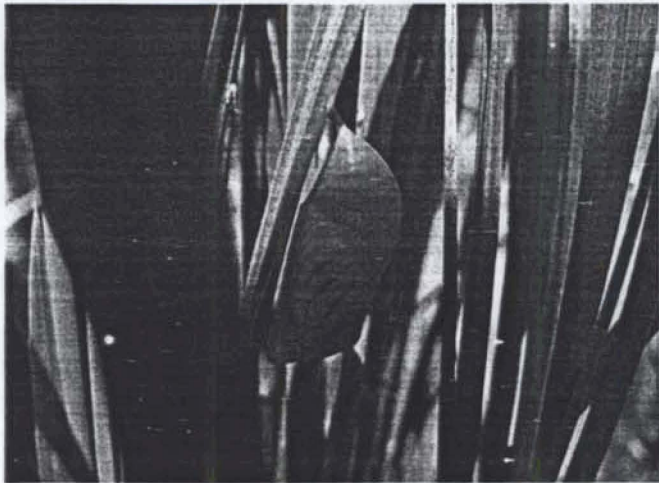
Colan photos?



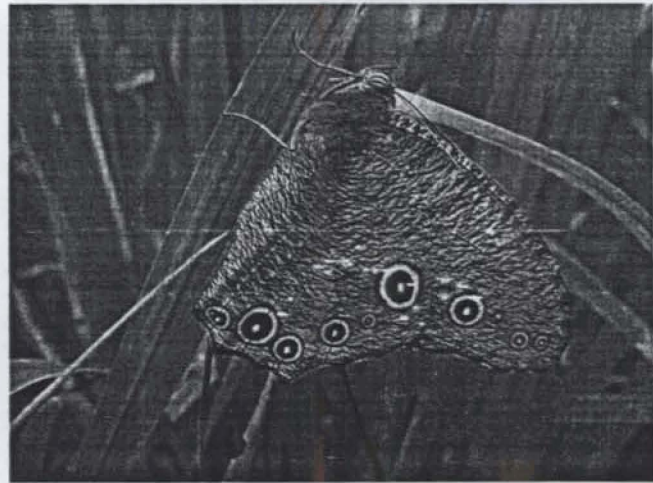
a. *Melanitis leda* final instar larva



b. *Melanitis leda* pupating



c. A young pupa of *Melanitis leda*

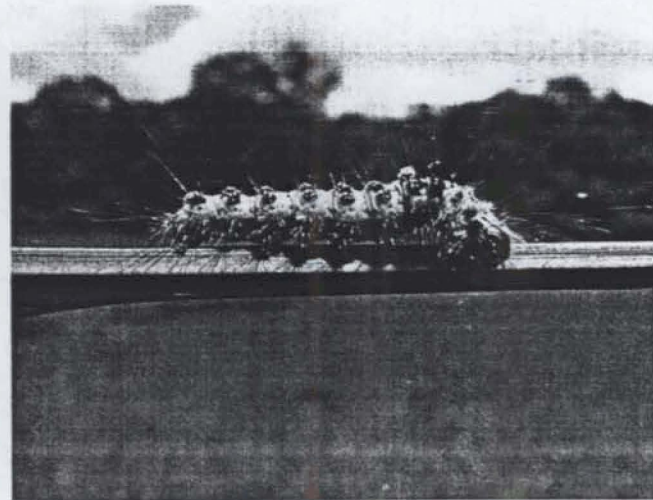


d. An adult *Melanitis leda* butterfly

colabam photoes



e. Larva of *Cnaphalocrocis medinalis*, and the mode of its damage



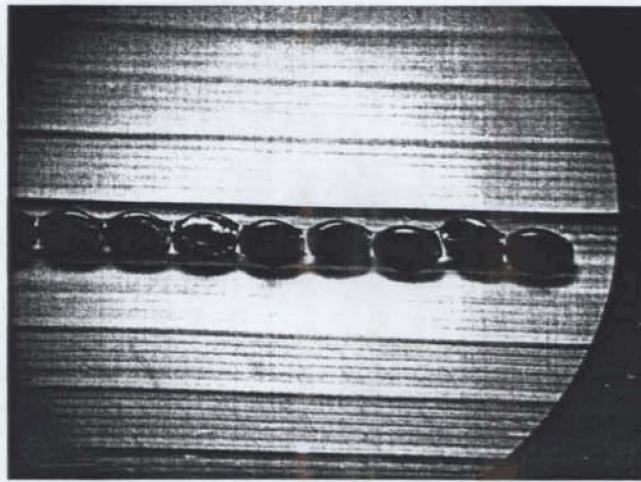
f. *Euproctis* sp. larva

Plate 4

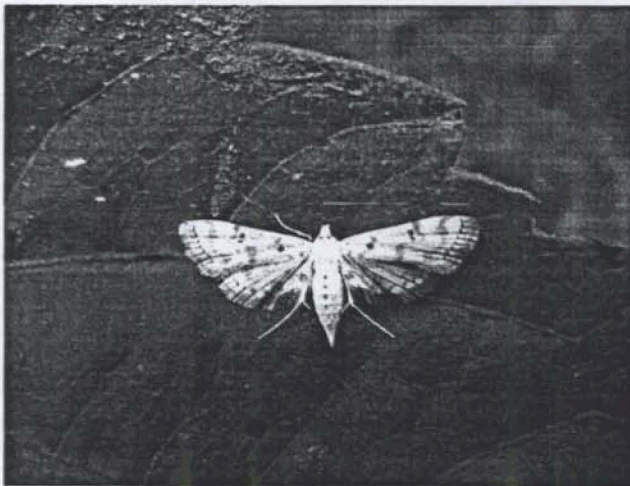
205
4



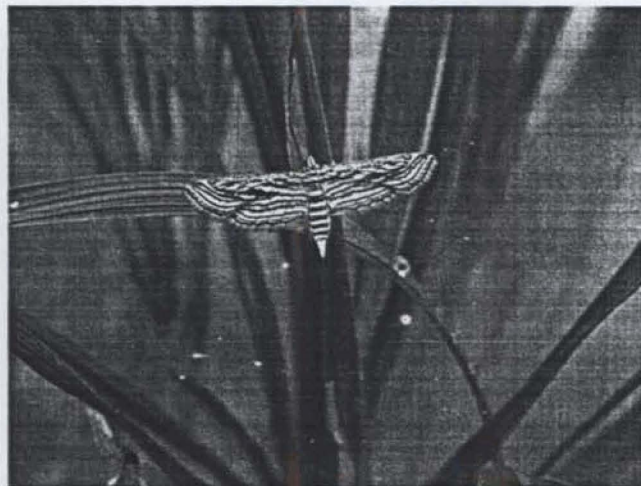
a. *Leptocorisa acuta* on rice crop



b. Egg clutch of *Leptocorisa acuta*

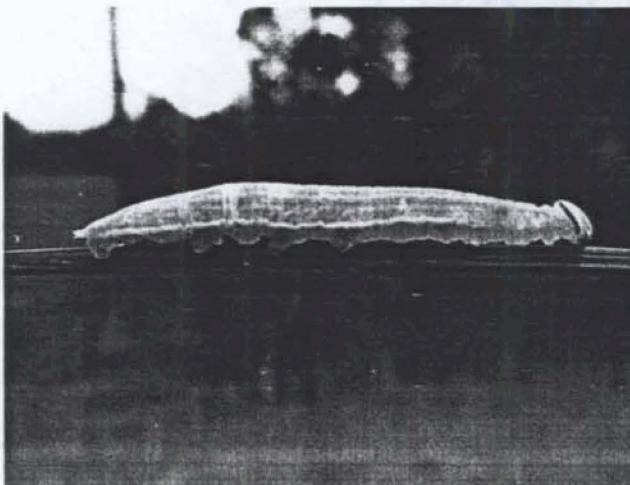


c. *Nymphula depunctalis* adult

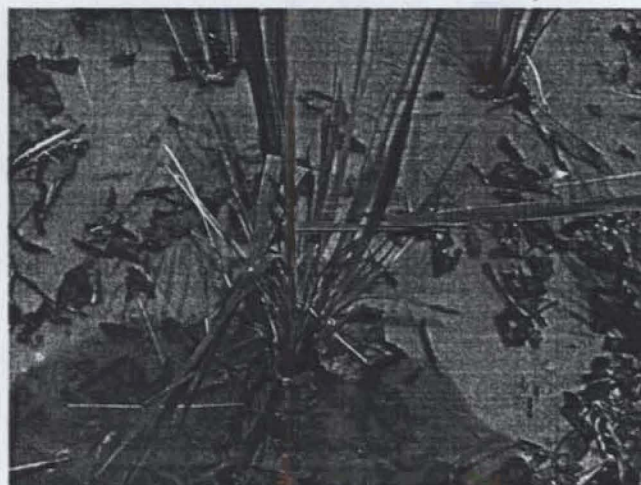


d. *Nymphula fluctosalis* adult

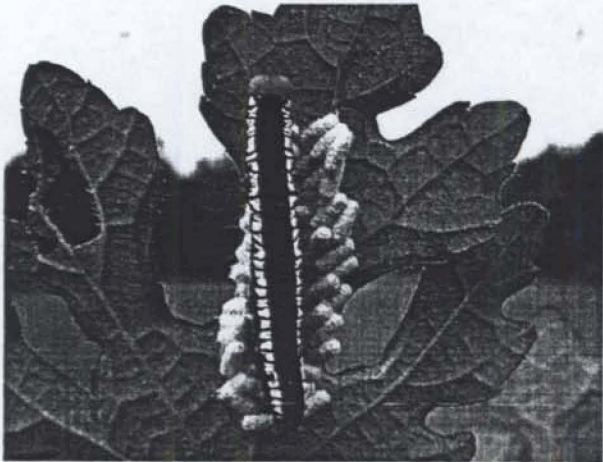
Colour by
photo



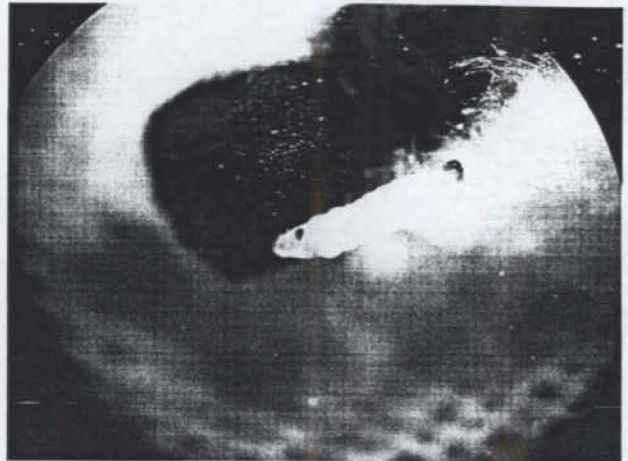
e. *Pelopidas mathias* final instar larva



f. Leaf cases of *Pelopidas mathias* larvae



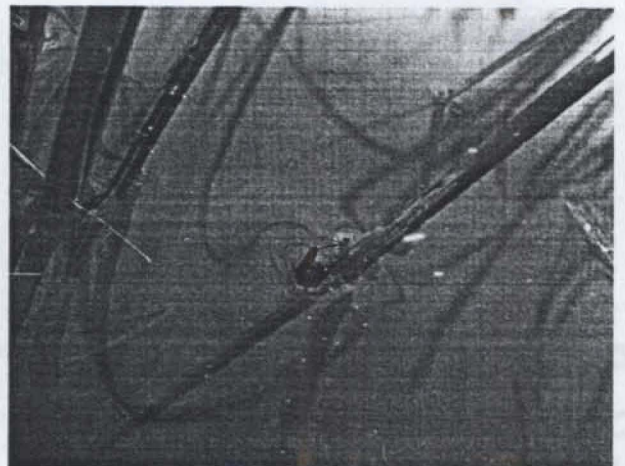
a. *Apanteles* sp. (Braconidae) pupae on non-pest larva seen on wild plant on paddy bund



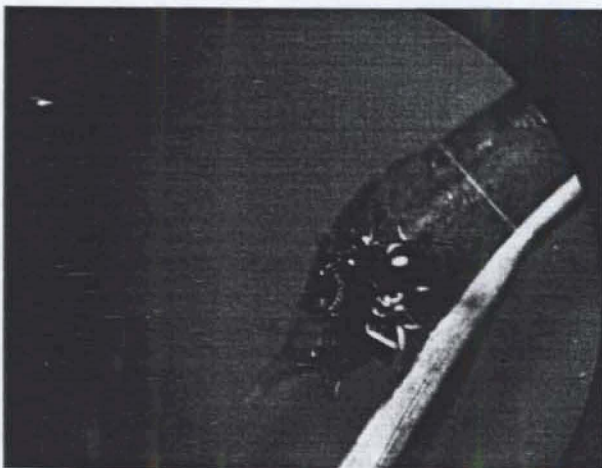
b. *Cotesia* sp. (Braconidae) larva coming out of parasitised rice swift larva



c. *Litochila* sp. (Ichneumonidae) female in search of *N. depunctalis* pupa



d. *Litochila* sp. (Ichneumonidae) sinking beneath water in search of *N. depunctalis* pupa

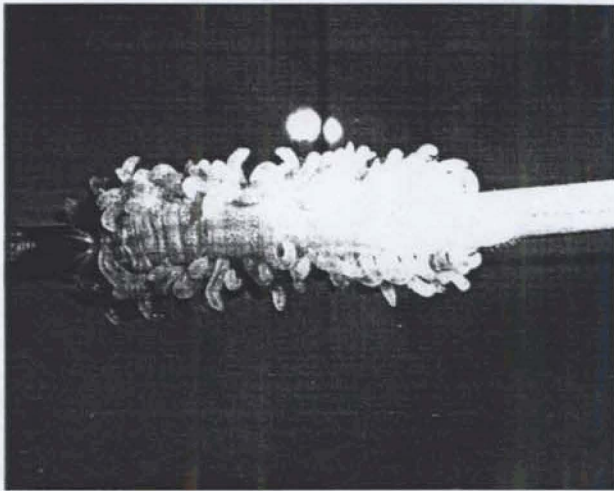


e. *Brachymeria lasus* adult emerging out of *Pelopidas mathias* pupa

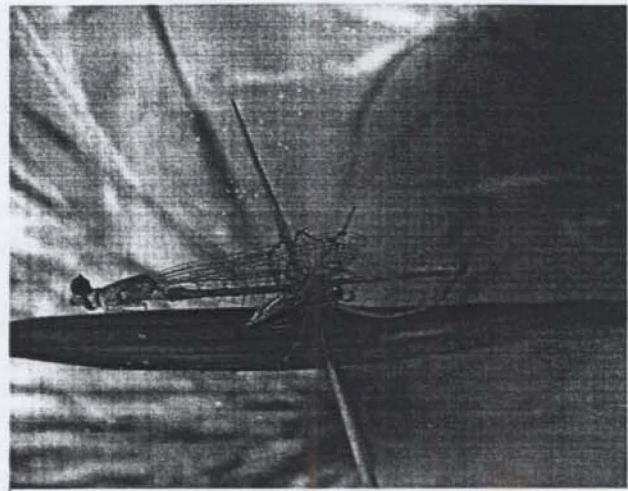


f. *Brachymeria lasus* (Chalcididae) in paddy field

Isolan phetae?



a. *Apanteles* sp. (Braconidae) emerging out of rice swift larva



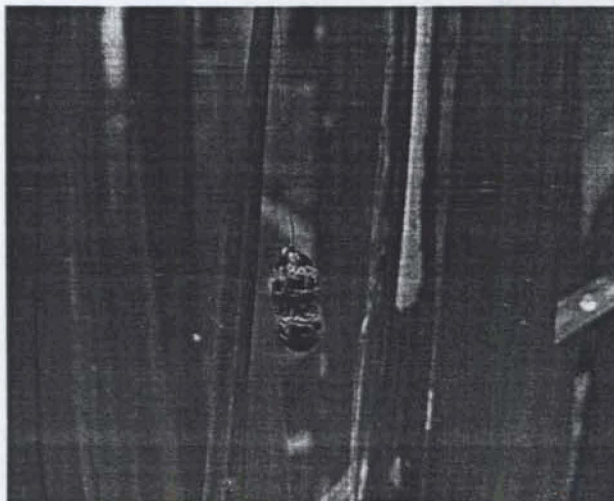
b. *Oxyopes* sp. (Oxyopidae) predated on a damsel fly



c. A damsel fly feeds on a *Nymphula depunctalis* adult



d. *Oxyopes* sp. feeds on *Scenocharops sinui* (Ichneumonidae), novel pupal parasitoid of *C. medinalis*



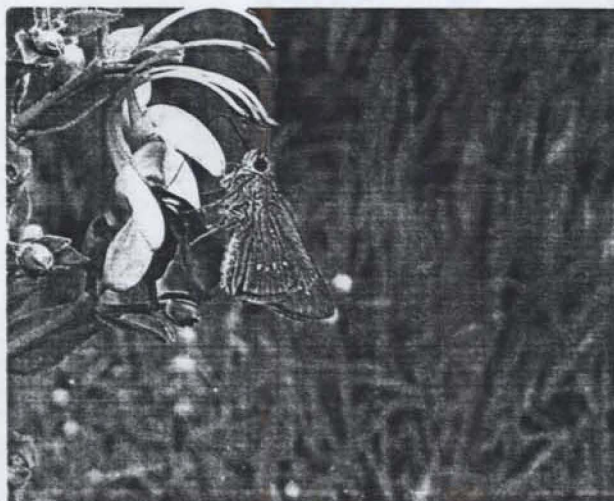
e. Puparium of *Charops* sp. (Ichneumonidae), host unknown



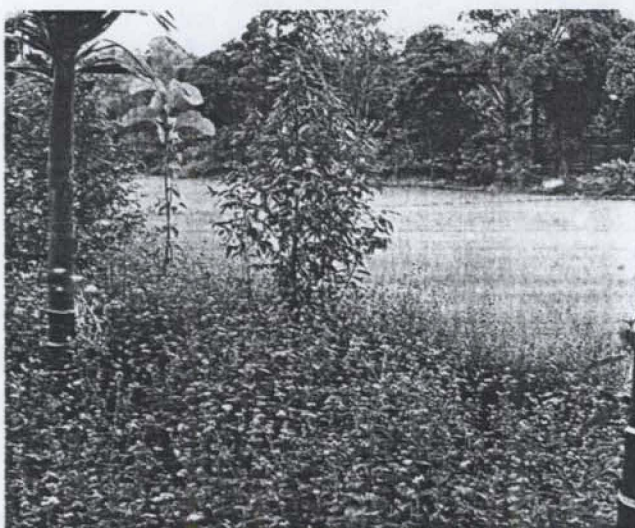
f. *Oxyopes* sp. feeds on *M. leda* larva



a. A skipper feeding nectar on *Justicia simplex*, a common weed seen on paddy bunds



b. Rice swift feeding nectar on *Clerodendron serratum*



c. *Ageratum* sp. rich Areca orchard corridor habitat



d. *Impatiens diversifolia* rich paddy bunds

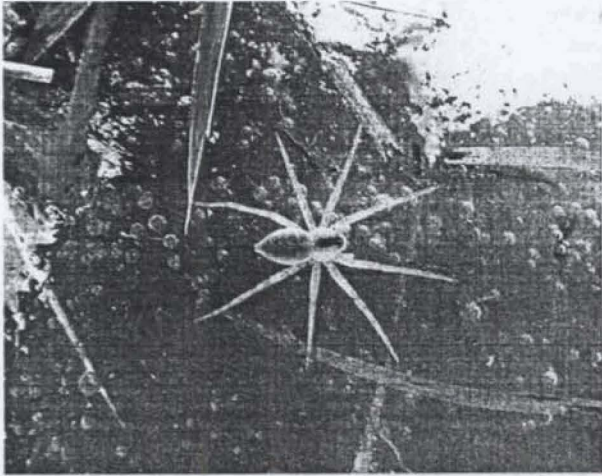


e. *L. acuta* feeds on a Cyperacean weed seen abundantly on paddy bunds during crop season



f. *I. diversifolia* rich Acacia plantation floor

209 16



a. *Pisaura sp.*, a common water spider seen in the water logged field



b. *Lycosa sp.*, a common wolf spider seen on fallow ground



c. *Cicindela whithilli* feeding on an earthworm during nursery period of paddy field



d. *C. whithilli* scavenging on a grub in the paddy field



e. Flourishing tiger beetles in the paddy field by the onset of monsoon and cultivation practice

NB5642