Influence of extractive disturbances on forest bird communities in Shiwalik landscape, India

Thesis Submitted to
Saurashtra University,Rajkot,Gujarat

For the Award of the Degree of
DOCTOR OF PHILOSOPHY
IN
WILDLIFE SCIENCE

by
MONICA

Wildlife Institute of India
Chandrabani, Dehradun
Uttarakhand, India
June 2015

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

CERTIFICATE

This is to certify that the thesis of **Ms. Monica** entitled "***Influence of extractive disturbances on forest bird communities in Shiwalik landscape, India***" is an original piece of work submitted to the **Saurashtra University**, Rajkot (Gujrat), for the award of **Doctor of Philosophy in Wildlife Science**.

Ms. Monica has put in more than six terms of the research work embodied in this thesis under our guidance and supervision. The work presented here has not been submitted to any other University or Institution.

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Place: W.I.I. Dehradun

Date: 23/06/15

Guide

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Department/College:

Executive Summary

Frequent extraction of plant biomass in the form of timber, firewood, fodder, and non-timber forest products (NTFP) by rural populations, is the most widespread disturbances in the tropical forests. These disturbances not only alter habitat characteristics but also affect habitat use, survival and fitness of biotic communities. Despite being a major cause of forest degradation, very few studies have actually investigated the relationships between these disturbances and biotic communities. It becomes difficult for natural resource managers to control or manage these disturbances in the absence supporting evidence and studies. Additionally it is essential to identify ecological indicators that could be easily used by managers to monitor such pressures.

Birds are highly sensitive to modification in their habitat and therefore amongst the best model taxa to examine and monitor impacts of these cryptic disturbances. In order to understand the dynamics of small-scale extractive disturbances and their effects on floral and faunal community, I undertook a study in Shiwalik landscape of northern India. One of the most important reasons for selecting this landscape was its significance for conservation of various large mammals and diverse assemblages of resident and migrant bird communities. At the same time, the landscape experiences a strong gradient of anthropogenic disturbances from near pristine to highly disturbed areas as it is situated in the midst of one of the most populated regions of the world. Realizing the conservation significance of this landscape, special protection has been provided to forested areas by designating them as protected areas. However, protected areas also suffer from biomass extraction carried out by local communities residing within and along the fringes.

My main research aims were to:

1. Identify the major causes of disturbance in three main forest type of this landscape and assess if disturbance depends on degree of protection.
2. Quantify impacts of disturbances on different layers of vegetation (tree and shrub) and examine changes in structure and composition of the habitat, if

any.

3. Investigate the response of birds community and foraging guild levels to habitat degradation in different forest types during breeding and non-breeding seasons.

4. Identify indicator bird species suitable for future monitoring of small-scale extractive disturbances in this landscape.

A contiguous stretch of the Shiwalik landscape between river Yamuna in the west and river Ganga in the east was selected to carry out this study. Within this area sampling sites were selected in three major forest types namely, Dry Plain Sal forest, Dry Shiwalik Sal forest and Moist Shiwalik Sal forest. I identified potential sampling sites, across a disturbance gradient. Later, in each forest type, I selected 10 sampling grid, totaling to a 30 grids across the landscape. Each grid had an area of 1 km^2 and a surrounding buffer of at least 250 m on each side. In each grid, I laid nine systematic intensive sampling points with inter-point distance of 250 m.

At each intensive sampling point, I quantified vegetation structure and composition, anthropogenic disturbances and birds. Each site was visited at least six times covering one breeding and one non-breeding season to understand the seasonal changes in disturbance regimes and bird communities. Sampling grids of both dry Shiwalik sal forest and dry plain sal forest were largely located in the western part of Rajaji National Park and Shiwalik Forest Division, while that of the moist Shiwalik Sal forest were located in the Dehradun Forest Division and Rajaji National Park.

I compared disturbance variables and also examined their degree of segregation across forest types. Relationship between proximity of human settlements and various disturbances was analyzed. I used conditional modeling approach to investigate the disturbance variables responsible for the (i) presence and (ii) abundance of an exotic invasive shrub *Lantana camara* in the study area. Bird density for grids and sampling points were estimated using Distance sampling approach. Birds were categorized into feeding guilds at coarser and finer scales. I used generalized linear mixed effect models to examine the response of vegetation and birds to various habitat variables. Due to vast seasonal changes in bird community composition separate models were built for breeding and non-breeding season.

I found a strong positive correlation among disturbance variables at landscape scale which indicate synergistic behavior of small-scale extractive disturbances. Dry Shiwalik Sal forest and Dry Plain Sal forest faced higher lopping and livestock grazing pressures compared to Sal *Shorea robusta* dominated moist forest. Village density explained lopping and grazing disturbance but level of protection (national park *vs* forest division) governed firewood and timber extraction.

Small-scale extractive disturbances have significantly modified the vegetation structure at both shrub and tree layer across forest types. It especially resulted in the decline of (i) canopy cover and (ii) shrub height. The major causative agent for native shrub cover loss in the Dry Plain Sal forest and Moist Shiwalik Sal forest was past timber extraction whereas in the Dry Shiwalik Sal forest it is the livestock grazing. Small-scale extractive disturbances have not modified the tree species composition as yet but has significantly altered the native shrub composition. These disturbances have led to invasion and spread of, one of the world's most invasive species, *L. camara* in the understory of all forest types. Such changes in vegetation structure and invasion of exotic species are expected to modify vegetation composition in future.

Over two years of sampling period a total of 173 bird species was recorded from the study area through 19184 observations. Bird communities in all these forest types are different during breeding and non-breeding seasons with the arrival of altitudinal, local, long-distance and passage migrants. Bird species richness and densities across all forest types were usually higher during breeding than non-breeding season.

L. camara cover increased the overall bird richness and density across all forest types and seasons. It also increased similarity in bird composition across sampling plots within Dry Plain Sal forest. Coefficient of variation of tree crown cover, an index of horizontal heterogeneity, was another important variable which positively influenced bird species richness during breeding season. Out of disturbance variables, firewood collection resulted in low species richness across seasons. Small-scale extractive disturbances led to increased similarity in bird composition among sampling plots. For instance, grazing in hill forest and firewood collection in dry and moist forest had resulted in increased similarity in bird community composition among sampling plots.

At the plot level, I did not observe any trend in guild densities across disturbance gradient. Guilds with different sensitivities to small-scale extractive disturbances were identified. Fine foraging guild with insect diet exhibited high sensitivity to disturbances. Canopy and understory-insectivores decreased in abundance with increasing disturbance. Guilds with fruit diet were benefited by *L.camara* cover. Granivorous and omnivorous birds increased with increasing disturbances.

A total of 66 species of birds emerged as indicators of overall disturbance in three forests. Highly disturbed areas were indicated by generalist species whereas specialist species were associated with less disturbed habitats. Jungle babbler *Turdoides striata*, Spotted dove *Streptopelia chinensis*, Jungle crow *Corvus macrorhynchos* indicated highly disturbed areas whereas species specialized in foraging strategy or substratum such as Jungle prinia *Prinia sylvatica*, Emerald dove *Chalcophaps indica*, Great tit *Parus cinereus* indicated less disturbed areas.

Species specialized in foraging from bark of tertiary branches such as Great tit *Parus cinereus* and Nuthatches decreased in abundance with increasing disturbance due to firewood and small-timber extraction. Livestock grazing led to decline in abundance of understory birds such as Jungle Prinia *Prinia sylvatica* and Red Junglefowl *Gallus gallus*. However, understory generalist species such as Himalayan Bulbul *Pycnonotus leucogenys* and Red-vented Bulbul*Pycnonotus cafer* increased with increasing lopping pressure. Increment in density of such species could be attributed to high density of *L.camara* in disturbed areas. Highly degraded areas of all forest types were indicated by similar set of bird species indicating homogenization of bird community. Interestingly, few migrant bird species were also responded strongly to extractive disturbances. Hume's Leaf-warbler *Phylloscopus humei* decreased significantly with increasing timber extraction whereas Pied Bushchat *Saxicola caprata* and Slaty-blue Flycatcher *Ficedula tricolor* increased with increasing lopping pressure.

Species responding significantly to disturbances were later ranked for characteristics essential for their utility in monitoring program. With the help of literature, I identified four parameters for increasing the robustness of indicator species. In addition to the sensitivity to disturbance, detection in field, seasonal availability in the landscape and cross-forest distribution were the criteria used for ranking and selecting the final set of top indicators. A total of 15 species emerged as top indicators for monitoring high and low-level of disturbances.

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I owe a special thanks to my parents. They always encouraged me to follow my dreams. My brother bullied, fought and irritated me but at the end of the day supported me and helped me to catch those trains, buses and flights which were leading me towards my different dreams. He has been a very quiet supporter all along this journey. I would also like to thank my sister-in-law and nephew for bringing a smile on my face whenever I felt down. I am blessed to have such a loving and supporting family.

Finally, I would like extend my deepest gratitude to a very significant companion, Lakshminarasimha R., who joined late in my journey but has had a strong influence on my work. Narasimha encouraged me to push barriers and strive for perfection in work. His passion for reading and learning new things is contagious even for a person like me. He not only taught me new programs (LaTex and ggplot 2) that helped me to improve the presentation of my work but he was also there whenever I was stuck and failed in my attempts of learning. There were times when I had doubts about my potential but his unwavering belief in me helped me in overcoming my doubts.

Monica

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Sabuj, Shazia and Dutta had been, and continue, to be very strong support system during all ups and downs in my personal and professional spheres of life. I thank Sabuj for helping me to look forward and have a positive but practical approach in life. Shazia not only helped in adapting to a new work place but was also there when I was down with self-doubt. She fed me like a sister, danced for me to cheer me up and at times shouted at me to bring me back on track. I am thankful to Tapajit Battacharya, Sabuj Bhattacharya and Dr. Malvika Onial for providing valuable suggestions on various chapters of my thesis. I am thankful to Shikha Bisht for providing editorial inputs on the thesis at a very short notice. I thank Mr. Ninad Mungi and Ms. Swati Saini, for providing invaluable help in better understanding of GIS and preparation of study area maps. I am grateful to Dr. Abishek Harihar for generously providing data on Gujjar settlement locations within the study area. Thesis has been written using LaTex software and the majority of the graphs have been prepared using ggplot 2.

I am grateful to Dr. Srikant Chandola, former Chief Wildlife Warden, Uttarakhand and Sh S. S. Sharma, Chief Wildlife Warden, Uttarakhand for per-

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Monica

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CHAPTER 1

Introduction

1.1. Small-scale extractive disturbances

Natural disturbance has been an integral part and a key shaping force in almost every ecosystem (Turner, 2010). As defined by White & Pickett (1985), disturbance is "*any relatively discrete event in time that disrupts ecosystems, community or population structure and changes resource, substrate availability, or the physical environment*". By interacting with landscape features, disturbances create areas differing in structure and composition (Levin & Paine, 1974). Such spatially heterogeneous landscapes provide diverse habitat so that more species can be packed in, thereby enhancing biological diversity. It is an important evolutionary force as species evolve spectrum of abilities to cope with changes in their habitat condition (Grant & Grant, 1993; Brown & Brown, 1998). Disturbance has a significant role in maintenance of biodiversity by reducing competition and unlocking resources for the pioneer species through removal of dominant species. Even the high diversity of the coral reefs and tropical forests is attributed to the disturbances (Connell, 1978a). However, unlike natural disturbances, the anthropogenic ones are becoming more common and intense in today's scenario largely due to increased human population and associated resource use.

According to the Millennium Ecosystem Assessment, humans have immensely altered every possible ecosystem in past 50 years more than any other time in history (Hassan et al., 2005). Humans being the major causative agent of all disturbances, led to the suggestion from researchers including Paul Crutzen, a noble laureate and an atmospheric chemist, to name this era as "Anthropocene" (Dirzo et al., 2014; McGill et al., 2014; Lewis & Maslin, 2015). "Great acceleration graphs" constructed by the International Geosphere Biosphere (IGBP) program present indicators of human and Earth's well-being. According to these graphs, the economy has undoubtedly improved especially in developed countries but at the great cost of worldwide extinction of many species (Dirzo et al., 2014), loss of valuable ecosystem services and loss of tropical forest (Steffen et al., 2015). Even the natural disturbance regimes have been altered by humans, making ecosystems less resilient to future disturbances. One good example is control of fire that leads to increased severity due to reduced landscape heterogeneity (Minnich & Chou, 1997).

Depending on the frequency and intensity, human induced disturbances or anthropogenic disturbances can be classified as *acute* and *chronic* (Singh, 1998). The former has a high intensity but low frequency, are highly destructive and easy to identify because of the extreme changes it brings in the habitat structure (Dellasala et al., 2004). Examples of acute disturbance include clear felling, shifting cultivation and fragmentation. In contrast, chronic or small-scale anthropogenic disturbances are frequent but subtle. Activities such as firewood collection, fodder collection, livestock grazing, non-timber forest products (NTFP) collection are examples under the latter category (Singh, 1998; Martorell & Peters, 2005). Such "small-scale extractive disturbances" are rather important to study as over-harvesting of resources is one of the major reasons of widespread pressure on the forests in developing countries (Hosonuma et al., 2012), including India due to high dependency of rural population on forests resources (Kothari et al., 1989).

In the following sections I first summarize the findings on effects of small-scale extractive disturbances on vegetation that forms the basic template of habitat and alteration of which could lead to invasion of exotic plant species. I then discuss the consequences of habitat modification on community and guild level of an important vertebrate taxa, i.e., birds, and potential loss of ecosystem services due to alteration in bird community. Finally, I discuss the potential and benefits of using birds as indicators of this particular category of disturbance.

1.2. Effects on Vegetation

Recent studies establish that extractive disturbances can cause significant changes in both vegetation structure and composition (Bhatt et al., 1994; Murali et al., 1996; Shankar et al., 1998; Tilman & Lehman, 2001; Sagar et al., 2003; Barve et al., 2005; Kumar & Shahabuddin, 2005). Studies on individual disturbance factors revealed that they could alter the habitat characteristics to a greater extent. For example, in Billigiri Rangaswamy Temple (BRT) wildlife sanctuary in southern

India, NTFP collection led to decline in density and basal area of trees with subsequent increase in the dominance of small woody species over the large ones (Shankar et al., 1998). Moreover, heavily disturbed sites had lower regeneration of harvested trees than the less disturbed sites (Murali et al., 1996).

Firewood collection in Sikkim Himalaya resulted in highly deformed canopy structure and disruption of normal girth class distribution of trees (Chettri et al., 2002). In Uttar Kannada district of Western Ghats, Bhat & Gadgil (1995) showed that complete removal of leafy biomass (also known as "lopping" at 100% wherein all branches of a tree are lopped) led to reduction in tree girth and increased production of leafy biomass through shoot regrowth. Also, canopy opening after lopping resulted in increased grass production.

Livestock grazing in Douglas-fir habitat in the University of Idaho's experimental forest altered vegetation composition by favouring weedy species, decreasing production, cover, frequency of major palatable grasses and dominance of the preferred species (Zimmerman & Neuenschwander, 1984). In woodland and riparian habitats, vegetation structure and composition altered significantly through a combination of grazing mediated trampling, changes in nutrient fluxes and loss or altered recruitment (Kauffman & Krueger, 1984; Fensham & Skull, 1999).

1.2.1. Facilitating Biological Invasion

One of the immediate effects of disturbance on any ecosystem is the release of resources (space, nutrient, water, light) by elimination of dominant species (Sousa, 1984; Tilman, 1985). Availability of resources allows colonization by species with ruderals life history traits that could be native as well as non-native.

In the dry tropical forest of Sariska Tiger Reserve, India, biomass extraction caused higher abundance of native (*Adathoda vasica*) and exotic weeds (*Cassia tora* and *Prosopis juliflora*) in the highly disturbed areas (Kumar & Shahabuddin, 2005). Invasive species in particular benefit more by disturbances in their non-native ranges due to the no or low-availability of native enemies (pathogens, predators) (Liu & Stiling, 2006), better competitive abilities than natives and differential response of native species to disturbance (McIntyre & Lavorel, 1994; Lake & Leishman, 2004). Although disturbance facilitates invasive species, humans play an important role of introducing the species to novel areas (Wilson et al., 2009). Similarly, small-scale extractive disturbances such as firewood collection and grazing involve movement of humans from agricultural and semi-urban areas into the forest transporting propagules of native and non-native weeds (Gardener, 1993; Mack & Lonsdale, 2001; Chaneton et al., 2002).

Non-native/exotic species affect native species by altering the resource availability and disrupting the essential mutualistic interactions such as seed-dispersal and pollination (Traveset & Richardson, 2006). Moreover, non-native species can influence the disturbance making the ecosystem more vulnerable. For example, invasion of alien grass, *Bromus tectorum* in western North America has significantly altered the fire frequency by increasing the fuel load (Whisenantet al. , 1990). These modifications have not only adversely affected native grass species but also the faunal assemblages dependent on the native grasses for forage and cover such as sage grouse, black-tailed jackrabbit and Paiute ground squirrel (Knick et al., 2003). In India, *Lantana camara*, an exotic invasive from Central and South America, has similar effects on natural fire regimes (Hiremath et al., 2005). *L.camara*, a woody perennial benefits from fire which break its seed dormancy and leads to more aggressive comeback. Increased biomass set the stage for the next fire event. In such situations, both disturbance and invasive species facilitate each other (Hiremath et al., 2005).

1.3. Effect on Birds

Birds are highly susceptible to changes in habitat caused by human use and modification (Raman et al., 1998; Thiollay, 1999; Lohr et al., 2002). However, the effect of disturbances could vary depending upon the organizational level (community, population and species) and classification (foraging guilds, generalist vs specialist) under consideration.

Effect of disturbances on bird community attributes have largely established the negative relationship between the two. For example, Martin & Possingham (2005) investigated the effect of livetsock grazing in Australian woodland and riparian habitats. However, densities of majority of bird species in both the habitat declined (31 out of 62 and 29 out of 58) with grazing but density of few species increased with grazing. Similarly, in dry tropical forests of Sariska Tiger Reserve in India, Shahabuddin et al. (2006) found lower bird species diversity in disturbed sites and significant differences in species composition across disturbance levels.

Studies with analysis at the species level revealed fluctuations in abundance with disturbance index. Aigner et al. (1998) showed decline in population of two birds species the Pacific-slope Flycatcher, *Empidonax difficilis* and the Hutton's Vireo *Vireo huttoni* due to firewood harvesting from oak-pine woodland. In South Africa, Du Plessis (1995) has provided evidence that at least two tree cavity-dependent bird species, Cardinal Woodpecker, *Dendropicos fuscescens* and Southern Black Tit, *Parus afer* disappeared for a long period (from 1988 till 1991) from a woodland remnant that was heavily harvested for firewood, whereas they were still present in an un-harvested area. Increasing grazing frequency in riparian habitat in Oregon caused decline in abundance of passerine birds (Taylor, 1986). However, Evans et al. (2006) found that low intensity livestock grazing improves the breeding abundance of a common upland passerine, the Meadow Pipit *Anthus pratensis*, after two years. In Sikkim Himalaya, Chettri et al. (2002) observed that canopy opening was the major change in vegetation structure due to extractive pressures that enhanced bird richness by favouring generalist species.

1.3.1. Loss of Ecosystem–services

Birds are essential ecosystem service providers and therefore amongst the most appropriate taxa to study effects of disturbance on faunal communities. Species declines and/or local loss in degraded forests may also lead to cascading and catastrophic co-extinctions (Koh et al., 2004).

Seed dispersal by frugivorous birds, an important ecosystem service, is in jeopardy by habitat degradation. Disappearance of avian frugivores may have serious consequences for many tropical trees that have evolved to produce large, lipid-rich fruits adapted for animal dispersal (Howe, 1984) subsequently leading to the shift in plant species composition. Several examples exist of fruiting tropical trees that either failed to re-establish after harvest or declined in numbers in fragments where the frugivorous birds responsible for the dispersal of their seeds have declined or disappeared (Brash, 1987; Cordeiro & Howe, 2001, 2003).

The biological control of herbivorous insects by birds may be of value in both anthropogenic and natural forest settings (Tscharntke et al., 2008). Although it is clear that insectivorous birds play an important role in controlling outbreaks of herbivorous insect pests in agroforests (Perfecto et al., 2004), there are fewer studies with comparable results in natural forest stands (Van Bael et al., 2003a; Sekercioglu, 2006).

Loss of vultures from India and subsequent increase in rotting carcasses around human habitation is a stark example of essential yet under-appreciated role of scavengers (Terborgh et al., 2001). Therefore to conserve these complex and irreplaceable ecological services it is crucial to understand the impact of extractive disturbances on avifaunal communities.

1.3.2. Monitoring small–scale extractive disturbances using birds

Ecological monitoring is increasingly recognized as a tool to (i) identify new environmental concerns, (ii) to ensure sustainability of resource extraction from an area and (iii) to assess the effectiveness of management interventions. Information generated through monitoring could help decision makers and stakeholders to develop appropriate strategies to mitigate, adapt and respond to habitat modification. Long term monitoring of populations is considerably more valuable than sampling populations in time, especially where human disturbances are concerned (Johns, 1989). The Convention on Biological Diversity (Balmford et al., 2005) draws attention to the need of monitoring ecosystems, habitats, species, communities, genomes and genes. Since it is not possible, physically as well as logistically, to monitor each and every species or process, therefore the scientific community advocates the use of "indicators". Ecological indicators are the biological units sensitive to chemical, physical and other biological units (e.g., introduced species) and thus could be used by managers to monitor changes in the habitat due to natural or human activities. Although several criteria have been listed for an efficient indicator but the four most important criteria are: (i) they must be feasible and cost effective to sample, (ii) they should be easily and reliably identified, (iii) they should be functionally significant and (iv) respond to disturbance in a consistent manner (Dale & Beyeler, 2001).

Aves is one such taxon that meets all the criteria and thus is one of most suitable taxa to be used as ecological indicator. Järvinen & Väisänen (1979) while developing a blueprint of a monitoring system based on breeding land birds opined that in spite of their limited energetical role in most habitats, birds constitute a good monitoring tool on account of their ecological diversity. Birds also vary in their tolerance towards human disturbance; some are harmed by human impact but many populations respond favourably to even the most extreme environmental changes. Birds also have other advantages in monitoring projects such as availability of several standardized census techniques, relatively easy field identification, and availability of basic information.

Canaries were perhaps the first birds to be used as indicators of carbon monoxide pollution in mines (Burrell & Seibert, 1916). Several studies have shown differential indicator potential of communities, foraging guilds and species (O'Connell et al., 2000; Schmiegelow & Mönkkönen, 2002). Woodpeckers, particularly, have been shown as excellent indicators of species richness of overall bird community as well as of habitat condition (Mikusiński et al., 2001; Drever et al., 2008; Kumar, 2011).

1.4. Research rationale

Small-scale extractive disturbances are a common and widespread phenomenon in the forested areas of our country. In some areas people have legal rights to collect forest produce and graze their livestock while in other areas people meet their needs illegally. Even protected areas set aside for biodiversity conservation are not unaffected by these pressures (Kothari et al., 1989).

The Shiwalik landscape in India is one such area that has high conservation value due to its rich biodiversity and simultaneously supports high human (Cincotta et al., 2000) and livestock populations (Robinson et al., 2014). Forest resources are utilized by the forest dwelling communities and local villagers for their sustenance and livelihood for a very long time. However in past few decades, human population in this landscape has increased tremendously creating more pressure on the forest resources (`www.censusindia.gov.in`). Studies on biotic disturbances have been carried out in Central Himalaya (Kumar & Ram, 2005) and Sal dominated areas of Uttar Pradesh (Pandey & Shukla, 2003) on vegetation diversity without quantifying disturbance. Moreover, there are not many studies in the forests of Shiwalik landscape of northern India that have analyzed the response of faunal communities to these disturbances.

Small- scale disturbances never occur singly and often interact with other disturbances and have cumulative or additive effects on biodiversity (Singh, 1998). However, only a handful of the conducted studies has investigated the concurrent effect of different disturbances on habitat and biotic communities (Ramrez-Marcial et al., 2001; Martorell & Peters, 2005; Shahabuddin & Kumar, 2006). Considering the contemporary population growth rate of 20% in Shikwalik landscape (`www.censusindia.gov.in`), there is an urgent need to assess the impacts of these small-scale frequent disturbances on forests and faunal communities.

In this thesis, I identify the major disturbance regimes in three selected dominant forest types across the Shiwalik landscape and investigate the combined effect of various small-scale extractive disturbances on vegetation and bird communities.

The Shiwalik landscape forms a suitable study area to examine the impact of extractive disturbances on two taxa because it has (a) suite of small-extractive disturbances in operation with high spatial variability across the landscape (high to low disturbed areas), (b) a diverse array of target species (i.e. ca. 300 species of birds), (c) high diversity of vegetation types, and (d) a pre-existing database of baseline information on habitat, environment and demography from previous studies (Pandey et al., 1994; Edgaonkar, 1995; Johnsingh et al., 2004; Kurien et al., 2007; Harihar et al., 2014).

The main objectives of this study were:

1. To determine the extent of extractive disturbances in major vegetation types across Shiwalik landscape.
2. To study the impacts of extractive disturbances on habitat characteristics of forest birds
3. To study the response of forest bird communities to habitat and disturbance variables across forest types.

1.5. Organization of Thesis

My thesis is organized into seven chapters that include first two introductory chapters, followed by three main chapters and last chapter as concluding remarks. Chapter 1 deals with general concepts on effect of disturbances on vegetation and bird community as well as the significance of birds as ecological indicators. A review of literature on these subjects is provided in support of this study. Chapter 2 contains two sections, the first section provides a concise description of the study area and in second section I provide a detailed account of field methods.

Chapter 3 focuses on identification of major disturbance factors across three forest types within the study area and its effect on vegetation characteristics. In particular, I examine the correlates of observed disturbance with variables representing human density and protection level. I investigate the effect of disturbances on tree and shrub structural and compositional characteristics. Considering the current rapid spread of an exotic invasive plant species *Lantana camara* in the study area, I also examine whether small-scale extractive disturbances facilities its invasion.

Chapter 4 explores the differences in the response of breeding and non-breeding bird community to various disturbances across forest types. I investigate the respective role of disturbance, vegetation characteristics and an invasive plant species *L. camara* in explaining variation of bird species richness and density. As the birds have specific needs of nesting and food resources during breeding season therefore the analysis is done for both breeding and non-breeding seasons.

Small-scale disturbances also affect foraging substrates and food resources for many bird species. Therefore, in Chapter 5, I explore the effect of small-scale extractive disturbances, vegetation characteristics and *L. camara* at an important scale of bird foraging guilds. Response of both broad and fine foraging guilds is investigated using density as a response variable. Guild densities were estimated separately for breeding and non-breeding seasons.

In Chapter 6, I identify the bird species that could be utilized by the forest department and/or scientific community to monitor degradation of habitat due to over-harvesting of forest resources. To track the changes in the regimes of different disturbances, I identified indicators for all forms of small-scale extractive disturbances active in the study area. The identified indicators are further ranked for their usefulness in the monitoring program. Apart from their sensitivity to disturbance, detection in field, seasonal availability in the landscape and cross-forest distribution are the criteria used for selecting the final set of top indicators.

In Chapter 7, I conclude the thesis by summarizing of my findings and discuss the areas of research for future.

CHAPTER 2

Study Area and Field Methods

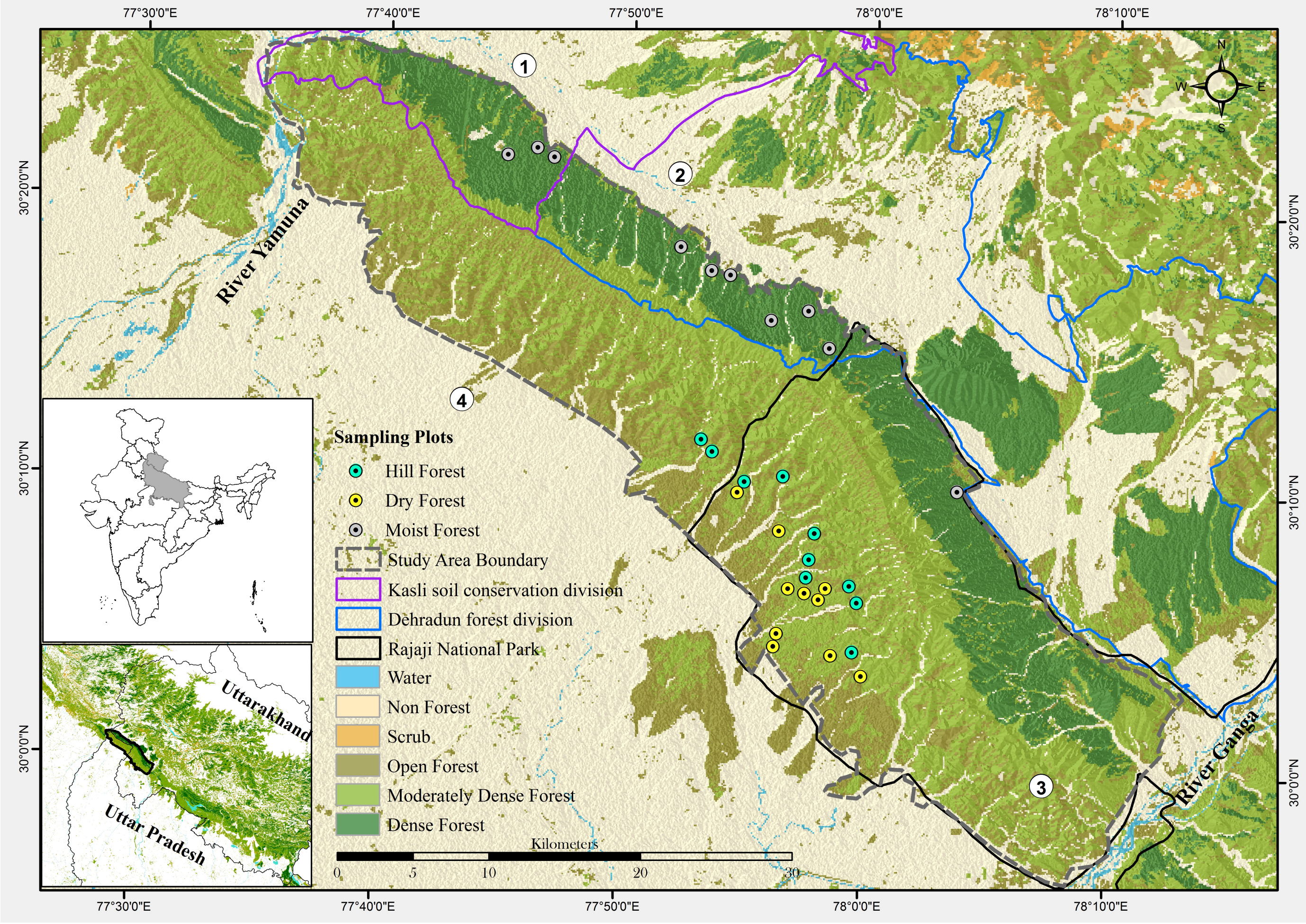
2.1. Study Area

2.1.1. Shiwalik landscape

I selected a contiguous stretch of Shiwalik landscape between River Yamuna in west and River Ganga in the east, of the Northwestern India to carry out this study (Figure 2.1). Shiwalik landscape (29°57' to 31°20'N and 77°35' to 79°20'E), also known as Sub–Himalaya, is the youngest mountain in India and it runs almost parallel to Lesser Himalaya. This landscape has high ecological significance due to the intermingling of taxa from the two biogeographic regions viz., the Himalayas and the Upper Gangetic Plains (Johnsingh et al., 2004). This landscape is also one of the most productive areas of the country and therefore suffers high human disturbance (Johnsingh et al., 2004; Wikramanayake et al., 2004). Current human density in this landscape is 1.7 times the country's average density of 382 people km^2 and is continuously growing approximately at a rate of 20 % annually (`www.censusindia.gov.in`).

The study area spans across two states, Uttarakhand and Uttar Pradesh and lies in the three administrative units, 1) Rajaji National Park, 2) Shiwalik Forest Division and 3) Dehradun Forest Division (Figure 2.1).

Figure 2.1.: Location of the study area within India and subsequently within two northern states, Uttarakhand and Uttar Pradesh (inset). Entire regions falls within three forest administrative units. Sampling plots within three forest types indicated with different colours.



2.1.2. Geology

Shiwalik landscape comprise the outermost hills of the Himalaya and stretches from the Indus to Brahmaputra with a single gap of 300 km from the Sapta Kosi to Manas river (Sivakumar et al., 2010). It is considered as the youngest formation in India dating back from a few thousand to 15 million years (Wadia, 1967). The composition of the Shiwalik deposits indicate presence of mainly alluvial detritus derived from the Central Himalayan ranges swept down by numerous Himalayan rivers and streams and deposited at the base of the foothills, subsequent to the Pleistocene glacial recession (Wadia, 1967). These deposits were later uplifted by the tectonic activities during the final phases of the Himalayan orogeny. On the paleontological grounds Shiwalik rock formation can be divided into three series, Upper, Middle and Lower Shiwalik. The Upper Shiwalik (1800–2750m) consists of conglomerates interbedded with clay and sandstone. The Middle (1800–2500m) comprises mostly sandstone and clay bed while the Lower (1200–1500m) consist of pseudo-conglomerates, sandstone and shale. Soil of this landscape is generally alkaline (pH=9.4) and low in organic matter due to minimal leaf litter as well as to rapid oxidation in high daytime temperatures (Grewal et al., 1987).

2.1.3. Physical features

The entire Shiwalik landscape is approximately 2,000 km long and width in some places can be as low as 16 km (Bhargav et al., 2009). The selected stretch of the Shiwalik landscape for the study is 74 km long and approximately 14 km wide. Altitude of the study area varies from *ca.* 300 to 1200 m above mean sea level. This region has a prominent north-west south-east ridge running through the middle of it. Northern side of the ridge slopes gently into the Dehradun valley and is characterized by luxuriant deciduous forest of *Shorea robusta* (Dipterocarpaceae, commonly known as 'Sal').The southern side of the ridge recognized for its rutted topography with a number of steep ridges emanating from main Shiwalik ridge and has narrow valleys between them. These valleys accommodate seasonally swift rivers locally known as "Rau" (dried river bed). In between, the ridge is characterized by sparse vegetation and grassy slopes.

2.1.4. Climate

The study area lies in the subtropical zone and has a moderate monsoon climate. The northern and southern aspects of the Shiwalik landscape have a distinct micro-climate with about 2-3°C difference in mean daily temperature. There are three distinct seasons in the study area, summer (March–June), monsoon (July–September) and winter (November–February). Mean minimum temperature in the area during January ranges between 3-5°C and in summer temperature can rise up to 44°C in June. Mean annual precipitation in the study area ranges between 1,600–1,800 mm. Most of the precipitation is received during July–September from the southwest monsoon. A few spells of winter rains are common during January–February which contributes about 5-10% of the annual precipitation (WII, 2005).

2.1.5. Vegetation

The flora of the Shiwalik region represent elements from peninsular India as well as temperate region of the Western Himalaya. Its outer fringes are dominated by members of Poaceae (Gramineae), Cyperaceae, Leguminosae, Scorphulariaceae, Asteraceae, Malvaceae and Euphorbiaceae. Studies on the flora reveal that the area has approximately 2000 species of the flowering plants. Interestingly, within the small pockets of moist forest, one could encounter the evergreen species having affinities with Western Ghats and Eastern Himalaya, e.g. *Schefflera venulosa*, *Diospyros embryopteris*, *Phobe lanceolota*, *Wallichia densiflora* and *Bischoffia javanica*. Two vascular plant species-*Eremostachys superba* and *Catamixis baccharoides*- are endemic to Shiwalik landscape. Different forest categories in this study area can been classified into the following categories (i)Moist Shiwalik Sal, (ii) Dry Shiwalik Sal forest, (iii) Dry plain sal,(iv) Mixed Deciduous Forest, (v) Mixed Scrub, (vi) Himalayan moist scrub, (vii) Subtropical Pine, (viii) Low Alluvial Savannah, (ix) Khair-sisso Forest, (x) Riverine and Hill Valley Swamp Forest , and (xi) Plantations. More than 150 alien invasive plant species have been reported from the two states within the landscape (Sekar et al., 2012). However, *Lantana camara*, *Parthenium hysterphorus*, *Ageratum conyzoides*, *Sida cordifolia*, *Cassia tora* and *Eupatorium adenophorum* covers a considerable area in all across the landscape.

2.1.6. Fauna and conservation importance

Topographic diversity and high productivity in this landscape has resulted in a rich array of fauna. It forms the northwestern limit of distribution for India's two charismatic mammal species Bengal tiger (*Panthera tigris*) and Asian elephant (*Elephas maximus*). Other mammalian fauna include three ungulate species, namely sambar (*Cervus unicolor*), chital or spotted deer (*Cervus axis*), and barking deer (*Muntiacus muntjack*) and an antelope-the nilgai (*Boselaphus tragocamelus*). The steep grassy slopes are inhabited by goral, a goat antelope (*Nemorhaedus goral*).

The largest administrative unit of the study area, the Rajaji National Park is also an important bird area (IBA) and therefore has a significant role in avifaunal conservation. The bird diversity of this region is high, with more than 300 species of birds reported by Pandey et al. (1994). Of these, 144 are residents, 89 are migrants and 53 are altitudinal migrants. This area is also important for the conservation of some raptor species that are facing global declines. Thirty-two species of diurnal raptors have been reported from Rajaji National Park. Out of these, three species belong to IUCN's critically endangered category (White-rumped Vulture *Gyps bengalensis*, Red-headed Vulture *Sarcogyps calvus* and Slender-billed Vulture *Gyps tenuirostris*), one endangered (Egyptian Vulture *Neophron percnopterus*), three vulnerable (Pallas's Fish–Eagle *Haliaeetus leucoryphus*, Indian Spotted Eagle *Aquila hastata* and Greater–spotted Eagle *Aquila clanga*), and two near threatened (Lesser Fish–Eagle *Ichthyophaga humilis* and Cinereous Vulture *Aegypius monachus*).

The Sal-dominated forests within the study area are known for its species–rich woodpecker assemblages exhibiting high variation in body size and foraging habitat (Kumar, 2011). At least 11 species including Asia's largest and vulnerable picid, the Great-Slaty Woodpecker (*Mulleripicus pulverulentus* (Lammertink et al., 2009) breed in different pockets of the study area. Three species of hornbills namely Indian Grey *Ocyceros birostris*, Oriental Pied *Anthracoceros albirostris* and Great Hornbill *Buceros bicornis* occur in the low-lying evergreen or moist deciduous forests of the study area. Migrant bird species come and occupy the forest during summer and winter season. Winter season is marked by vast influx of migrant bird species from Himalaya making mixed flocks of several species of leaf warblers, flycatchers, woodpeckers, drongos, shrikes etc. During summer several species of cuckoos, starlings and bee-eaters migrate to the study area.

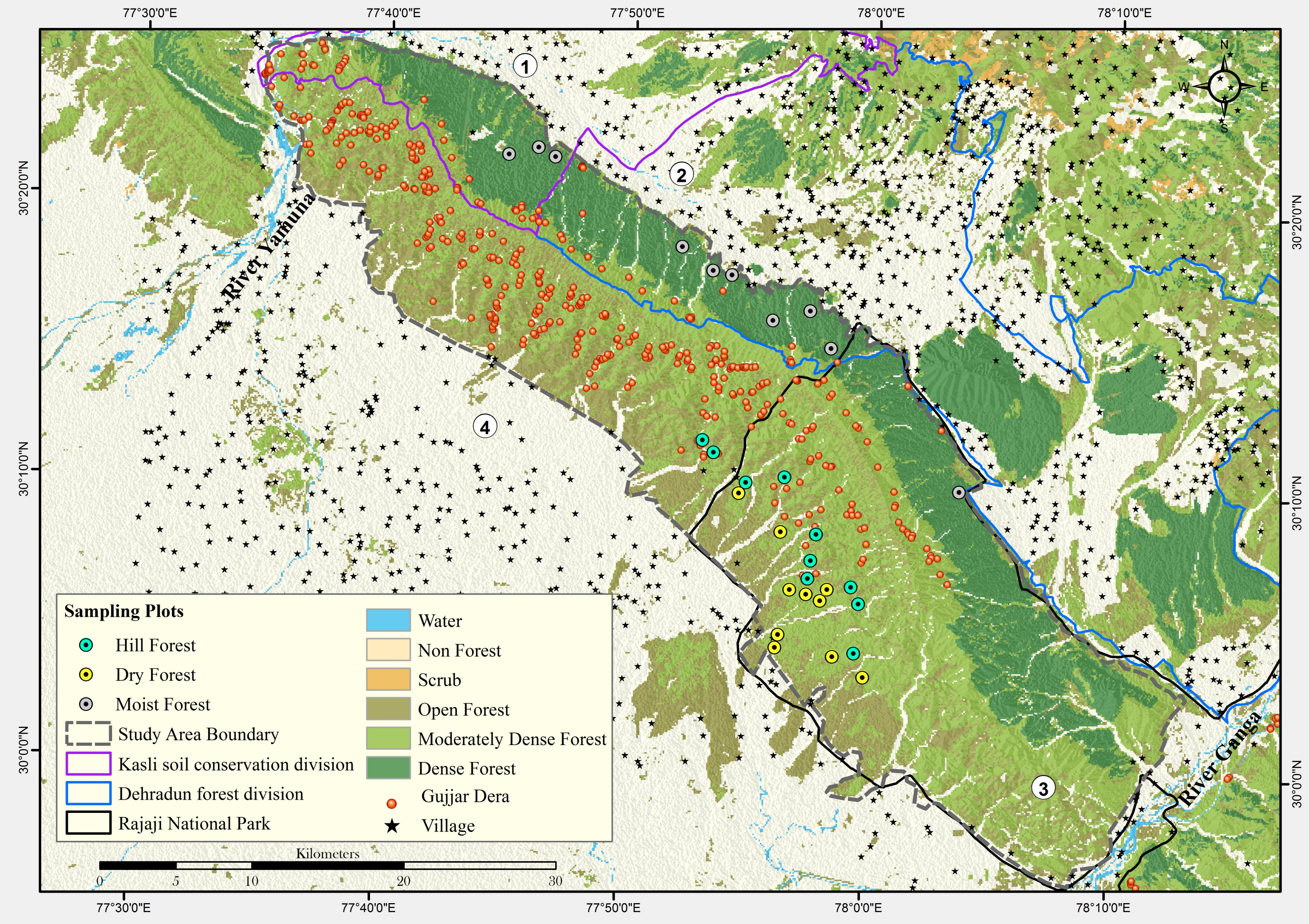
2.1.7. Anthropogenic Disturbance

This landscape is one of the most populated areas in the northern region of India (Cincotta et al., 2000). Human population within the major towns, e.g. Dehradun, Haridwar and Rishikesh adjacent to the study area has increased considerably leading to the expansion of these towns (WII, 2005).

The forest in this landscape have a long history of human use. Two major reasons for forest degradation in the study area are 1) Gujjar settlements located inside the forest and 2) villages along the boundary (see Figure 2.2).Gujjar is semi-nomadic pastoral community that inhabits various parts of the entire Shiwalik landscape for at least 110 years (Gooch, 2009). *Gujjars* rely heavily on the forest for lopped fodder resources (Figure 2.3 and Figure 2.4) for livestock to support their dairy product based economy. They also use forest to meet their demands of fuelwood and building material for their huts. In past, Gujjars followed transhumance and collected fodder in the foothills during the winter and in summer migrated to the high altitude meadows in the Himalaya. However, now partly due to the fact that local communities in the Himalaya do not want to share the resources with the Gujjars and partly owing to socio-economic changes within the community itself, most of the Gujjars have abandoned this traditional migration (WII, 2005). The stoppage of migration has resulted in their increased demands on the habitat in the landscape. Indiscriminate lopping year after year resulted in tree mortality and weed infestation.

Till 2003, as much as 86% of the Rajaji National Park was open to the Gujjar community for lopping and grazing. Almost a decade back, a major voluntary relocation drive of the Gujjar families from the Rajaji National Park to Haridwar (Pathri and Gaindikahta) helped in release of some pressure from the forest. During the first verification drive, to identify families, only 512 families were identified in the Park however delay in relocation process due to legal objection number of families increased over the years to 1390. Fresh verification process for the claims was carried out in the year 2009 and presently 190 families are residing within the park boundary and are utilizing the forest resources. As a result parts of study area are completely undisturbed for almost a decade.

Figure 2.2.: Location of villages and Gujjar dera within study area.



Taungya villages along the southern boundary of Rajaji National Park forms the second largest community with high dependency on the forest in this region (WII, 2005). These villages were settled by the forest department of British India in 1910 to practice taungya cultivation (Alexander et al., 1980). Taungya is a combination of agriculture and silviculture that involves cultivation of agricultural crops during the initial years of forest plantation. In independent India, gradually the focus of the forest department shifted from timber production to wildlife conservation and taungya practice came to a halt. However, taungya villages are still located at the edge of the Rajaji National Park with some of them as near as 1 km from the park boundary. Agriculture is still practiced by these villagers outside the Park on their small landholdings but poor soil quality and crop raiding by wild animals reduce the yield. Villagers on the southern boundary of the Rajaji National Park also harvest Bhabar (*Eulaliopsis binata*, Figure 2.3 A) grass from the slopes of Shiwalik hills. In the past Bhabar grass used to be an essential raw material for cottage and paper industry. Current use of Bhabar grass is restricted only for rope making. Since 1999 only permit holders can extract the grass which has resulted in decreases in quantity of grass collection. However, it is still a major source of income for the villages especially during the non-agriculture season.

Villages in the Dehradun Forest Division and northern side of the Shiwalik ridge have agricultural fields on the forest edge. These villages meet their demands of fencing poles and firewood from the forest. Their dependency on forest for fodder is lower than Gujjars and Taungya villages.

Figure 2.3.: Different small extractive disturbances in Shiwalik landscape A: Grazing, B: Lopping, C: Fire wood collection, D: Firewood collection.

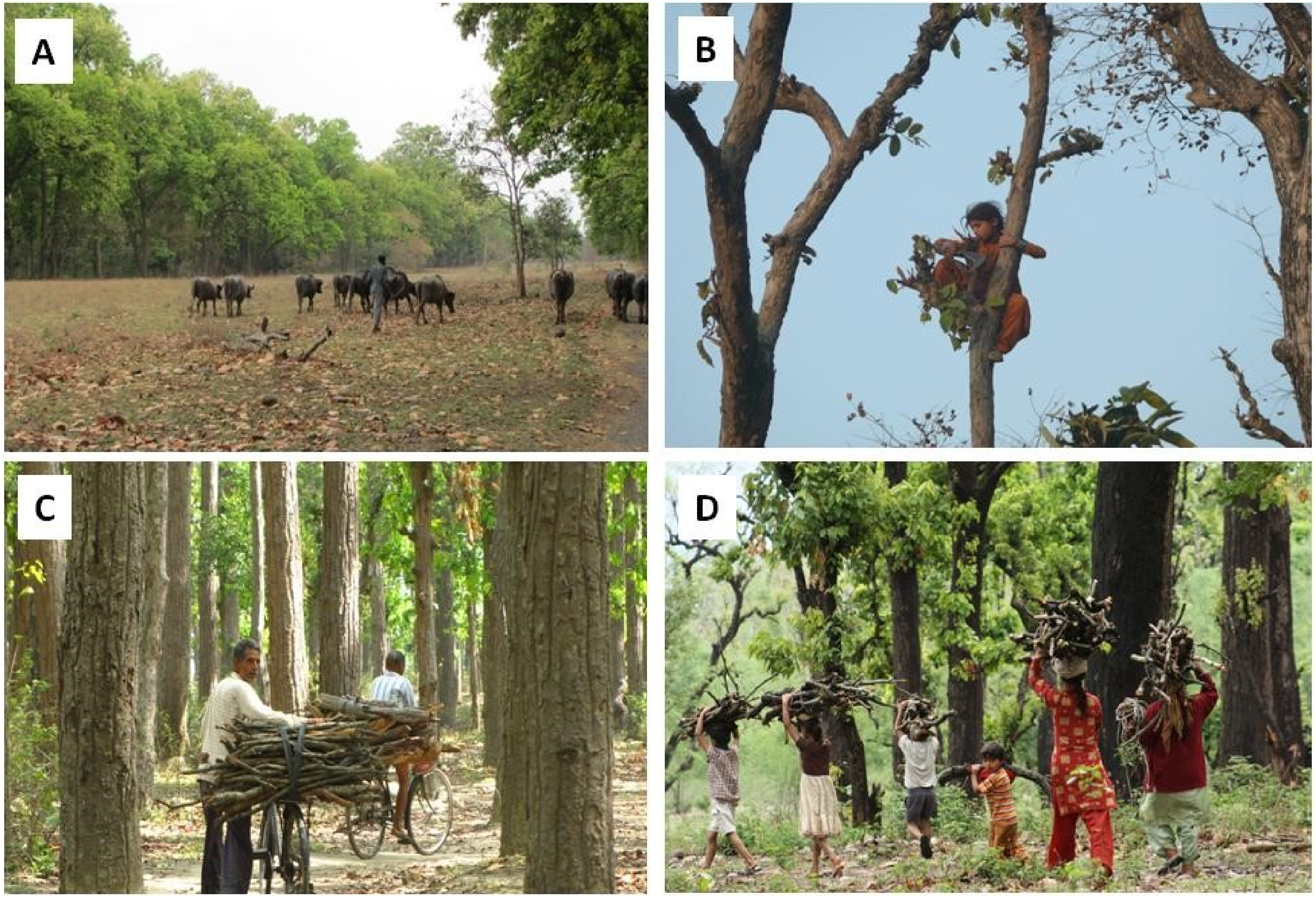


Figure 2.4.: Different small extractive disturbances in Shiwalik landscape. A: *Bhabar* grass collection, B: Litter collection, C: illicit timber extraction, D: Human trails.

2.2. Field Methods

2.2.1. Site Selection

Based on the maximum representation in the landscape, I selected three dominant forest types for the study. Selected forest types were Dry Plains Sal Forest ,Dry Shiwalik Sal Forest and Moist Shiwalik Sal Forest (Figure 2.1).

Dry Plain Sal Forest (category 5B/CIb, hereafter referred to as 'dry forest') is located in the south facing slope of the Shiwalik landscape (Figure 2.5 A). This region is characterized by its serrated topography with a number of steep ridges which emerge from the main Shiwalik ridge and have narrow valleys between them. Sal (*Shorea robusta*) forms the climax species of the forest succession. Sal is a dominant semi-evergreen tree species of the moist as well dry deciduous forest in India. Typical associates of sal are *Terminalia tomentosa*, *Terminalia bellerica*, *Lagerstomea parviflora* in the middle canopy. Understory is constituted by *Mallotus phillipensis*, *Ehretia laevis*, *Cassia fistula*, *Miliusa velutina* and *Holarrhena antidysenterica*. *Clerodendrum viscosum*, *Murraya koenigii*, *Colebrookea oppositifolia*, *Adathoda vasica* forms the shrub layer. *Lantana camara*, an exotic invasive, occupies a large area in this forest type and forms dense thickets in disturbed areas.

The forest on the slopes of the ridge with abundant *Anogeissus latifolia* is designated as Dry Shiwalik Sal Forest (category 5B/CIa; hereafter referred to as 'hill forest', Figure 2.5 B). Typical associates of *A. latifolia* in the canopy are *Acacia catechu*, *Buchanania lanzan*, *Terminalia tomentosa*,*Bauhinia variegata* and *Ougeinia oojeinensis*.Tree species in the middle story belongs largely to *Ziziphus xylopyra* followed by *Mallotus phillipensis*, *Cassia fistula*, *Ehretia laevis* and *Holarrhena antidysenterica*. Shrub layer is very sparse in this forest type and it characterized by *Woodfordia fructicosa*, *Nyctanthes arbortritis*, *Carissa opaca*, *Limonia accidisima*, *Helicteres isora*, *Flacourtia indica* etc.*Bauhinia vahlii*, a characteristic species of this forest type, is an important climber species valued by the gujjar community for its leaves and pods which provide fodder to their cattle. This forest type is also known for its luxuriant grass cover and scattered tree growth.

Third major forest type in the study area is Moist Shiwalik Sal Forest (3C/2Ca, herein after referred to as 'moist forest'). This forest type covers the northern side of the Shiwalik ridge which slopes gently into the Dehradun valley (Figure 2.5 C). Sal trees having a dense overstory canopy and little heterogeneity in the middle canopy with dense undergrowth characterize this forest. Trees of *Shrorea robusta* in the upper canopy are infrequently found associated with *Terminalia tomentosa*, *Lannea coromandelica*, *Adina cordifolia*, *Terminalia bellerica*. Shrub layer is dominated by *Ardisia solanacea*, *Murraya koenigii*, *Clerodendrum viscosum* and *Pogostemone plectranthoides*.

I first selected the potential sites across a disturbance gradient in all three forest types by consulting the forest management plans, forest officers and experts. Subsequently, I selected sampling sites from the pool of potential sites after reconnaissance surveys to assess the level of disturbance. Similarity in stand composition, surrounding matrix and distance from plantations were the additional criteria for the selection of the sampling plot. A total of 30 sampling sites were chosen across the entire landscape with 10 sites in each forest type (Figure 2.2). At each site a 1 km x 1 km representative area, which was reasonably homogenous, was delineated as a sampling grid (Figure 2.6). I selected grids that had a buffer (at least 250 m) of similar forest type all along the boundary to negate the edge effect (Watson et al., 2004). Within each grid I systematically marked nine sampling points on three parallel lines. Each line had three points placed at 250 m interval and also from the edge of the grid . Thus a total of 269 (3 forest types x 10 grids x 9 sampling point; one grid had only 8 points) intensive sampling points were marked within the study area (Figure 2.2).

Fieldwork of the study was carried out from the October 2009 till June 2011 covering two breeding (summer) and two non-breeding (winter) seasons. I utilized the winter of 2009 for selection of sampling sites, familiarity with birds and their calls, and trials of various sampling methods. Data was collected from 2010 to 2011.

2.2.2. Vegetation Sampling

Around each intensive sampling point, I laid concentric plots of 10 m and 5 m radius to enumerate trees and shrubs, respectively. All woody vegetation with 20 cm girth at breast height (GBH) or above was considered as tree. In each 10 m radius plot, I recorded number, species identity, GBH, canopy spread in two perpendicular diameters and height (bole and crown height) of each tree. Canopy cover was estimated using a convex spherical densiometer.

Shrub characteristics were measured in circular plots of 5 m radius nested within the 10 m radius plot. All woody vegetation less than 20 cm GBH was

Figure 2.5.: Forest type selected for the study. A. Dry plain Sal forest B. Dry Shiwalik Sal forest C. Moist plain forest.

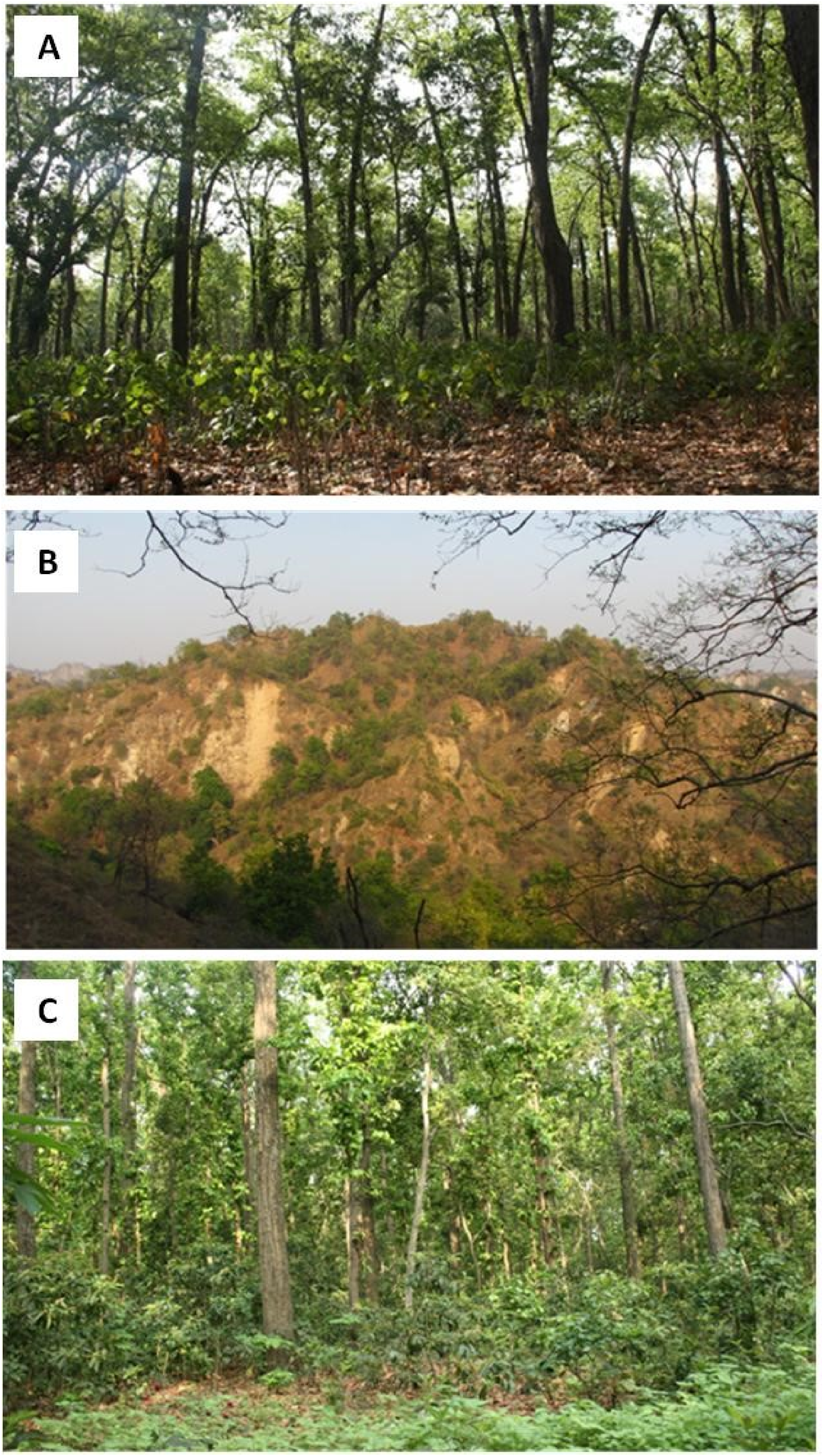
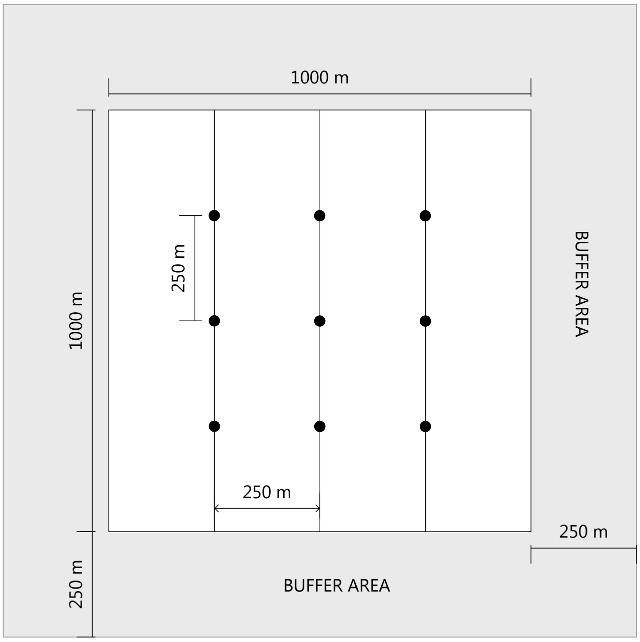


Figure 2.6.: Diagrammatic representation of the sampling grid. Each grid had an area of 1 km^2 with a buffer of 250 m on each side. Intensive sampling points(black dots) were laid at a distance of 250 m from the edge of the plot



considered as shrubs. I recorded the following parameters for each shrub; species identity, number of individuals, height and canopy spread in two perpendicular diameters.

This data was used to quantify the vegetation structural (basal area, tree height heterogeneity etc.) and compositional variables (richness and diversity) at both tree and shrub level. Canopy cover, tree and shrub crown cover are known to vary seasonally and therefore information on these variables was collected in both summer and winter season.

2.2.3. Disturbance Quantification

I quantified disturbance within a 20 m radius plot concentric around the vegetation plots. Within each plot, I recorded the percentage of lopped trees, lopping intensity on each lopped tree, number of dung pats, number and width of human trails

Table 2.1.: Variables used for quantifying disturbances with their respective abbreviation

Disturbance factor	**Variable quantified**	**Abbreviation**
Lopping	Number of lopped trees	perlopp
	Intensity of lopping	ilopp
Livestock grazing	Number of dung pats	dung
	Browsing signs	grz
Human usage	Number of trails	trailn
	Trail width	trailw
Firewood collection	Number of cut trees (<20cm GBH)	cuttr
Timber extraction	Number of cut trees (>20cm GBH)	cutst

passing through the plot, percentage of grazing, number of cut trees and cut stumps and presence or absence of fire signs (Table 2.1). Intensity of lopping on each tree was recorded on scale of 0-4 (Shahabuddin et al., 2006). According to this scale an intact tree with no sign of lopping gets zero value, tree with less than half of branches lopped gets a score of 1, tree with 50% of the lopped branches gets a score of 2, more than half of the branches lopped gets 3 and tree with all branches lopped gets 4. Percentage of grazing was estimated through ocular estimation of the browsing signs in the plot. To reduce the observer bias in estimating the lopping intensity and percentage of grazing, assessment was done by myself alone in all the seasons. To assess the seasonal changes in disturbance level, data was collected during summer and winter season for two consecutive years.

2.2.4. Avifaunal Sampling

Data on birds was collected using the variable radius point transect method (Bibby et al., 1992). Point transects were centered on the same circular plots which were used for collecting data on vegetation and disturbance. As the main objective of this study is to investigate the habitat preferences of bird community over a large landscape in tall, structurally complex vegetation types and rugged terrain, point transect was preferred over the conventional line-transect sampling (Reynolds & Trost, 1980). Moreover, well-spaced point transects could provide finer information than line-transects about the bird-habitat relationship if habitat parameters are quantified around the points (Bibby et al., 1992). All the point transects were spaced at least 250 m apart from each other to minimize the overlap in bird encounters (Hansen et al., 1995). Birds were observed for 5 minutes at each point after an interval of 2 minutes from reaching the point (settling down time). It was observed that there were no substantial additional observations beyond the 5-minute period. Moreover, the chances of double counting get enhanced for longer periods. Therefore total duration of 2+5 minutes was used for point transect across all forest types. All the birds seen or heard during this time (5 minute) period were recorded.

Additionally, number of individuals of each species (in case of sighting) and distance from the observer was also recorded. Distance was recorded using a laser rangefinder. Perch height of individuals was also recorded so as to find out the utilization of vertical dimension by birds. Perch height class of all the birds was recorded in case of all direct sightings. All the birds were identified using the standard field guides (Grimmett et al., 1999). Before starting the field data collection, I familiarized myself with the birds and their calls, by regular bird watching session in the Sal forest adjacent to Wildlife Institute of India and also within the campus which is abutting the study area and shares the similar avifauna.

All the point transects were conducted by myself alone to avoid observer bias. When there was a problem in correctly identifying a bird, it was recorded on the data sheet and identified after completing the count by referring to field guides and consulting the experts. Whenever bird could not be identified to the species level owing to difficulty in identification due to, aural cues (e.g. drumming in case of woodpeckers), small size or large distance from the observer (e.g. leaf warblers) only generic level information of the bird was recorded. Only the birds using the area during the count were recorded and all the flypasts were ignored.

Birds were observed every day only during the early morning hours when bird activity is the highest (Raman et al., 1998). This activity period differed depending on the season. In summer the counts ended before 3 hours from sunrise while in winters bird activity started a little late and continued till 3 hours from sunrise. Every morning only one plot comprising nine points was selected for bird sampling. All the points were visited for three mornings within each season. To capture the maximum species variation within a season all the points were visited after a gap of at least seven days. Again within a plot the order of visiting the points was reversed on each morning to negate the bias due to flushing of birds by observer. A total of 3228 point transects were undertaken during the entire study period.

CHAPTER 3

Impact of small-scale extractive disturbances on vegetation structure and composition

3.1. Introduction

Frequent biomass extraction in the form of grazing, timber extraction, firewood, fodder and NTFP collection by rural population is the most widespread disturbance in the forests of most developing countries, including India (Kothari et al., 1989; Singh, 1998). Removal of vegetation biomass due to these disturbances modifies structure and composition of the habitat which in turn has implications for the survival and fitness of the biotic communities (Daniels et al., 1995; Murali et al., 1996; Sagar et al., 2003; Kumar & Ram, 2005). In addition to changes in physical features, extraction of biomass also modifies microclimate of the stand by transforming abiotic feature i.e., temperature, humidity, light and wind (Sekercioglu, 2002). Such changes in microclimatic condition proves detrimental for germination and recruitment of shade loving tree and shrub species (Pinard & Putz, 1996). Simultaneously pioneer or weed species occupy the area due to reduced competition and increased light conditions resulting in altered vegetation composition and diversity (Murali et al., 1996; Sagar et al., 2003; Kumar & Shahabuddin, 2005; Bongers et al., 2009).

Compared to large infrequent disturbance events (e.g. clear-felling and fire) these disturbances never allow the system to recover due to continuous onslaught by humans (Singh, 1998). Most of the research on these disturbances pertains to single habitat type but considering differences in response of different forest types more such studies from diverse habitat types have been advocated

(Shahabuddin & Prasad, 2004; Saberwal & Rangarajan, 2005). Gradual modification in the habitat characteristics and difficulty in quantification of these disturbances are additional reasons for limited studies on these disturbances (Singh, 1998; Ramrez-Marcial et al., 2001; Shahabuddin & Kumar, 2006).

The aim of this chapter is to quantify disturbances among three forest types in my study area and ascertain its impact on vegetation structure and composition. Specifically, the following three questions were addressed:

1. What are the main agents of small-scale extractive disturbances in these forests, and whether disturbance regimes depend on forest types, proximity and density to human habitation, and protection level?
2. How do various disturbances affect vegetation structure and composition in different forest types?
3. Does small-scale extractive disturbances explain (i) presence and (ii) abundance of an exotic invasive, *Lantana camara*, in the study area?

This study was carried out in a contiguous stretch of Shiwalik landscape Three dominant forest types namely dry plain Sal forest (hereafter 'dry forest') in south of the Shiwalik ridge, moist Shiwalik Sal forest (hereafter 'moist forest') in the north–facing slope of Shiwalik ridge and dry Shiwalik Sal forest in the hilly tracts (hereafter 'hill forest') of the ridge (Champion & Seth, 1968) were for the study (Figure 2.1).

A total of 30 sampling grids of 1 km ^{2} were selected across the landscape. Each grid had nine sampling point and at each point, nested circular plots were established for enumerating vegetation characteristics, anthropogenic disturbances and bird community (Figure 2.6). Variable–radius point transect method (Bibby et al., 1992) was used to collect data on bird communities (See chapter 2 for details).

3.2. Data Analysis

3.2.1. Disturbance quantification and comparison among forest types

First, I examined if individual disturbance factors differed between forest types using Kruskal-Wallis multiple comparison test. Then, I tested if forest types differed in terms of overall disturbance regimes by multi-response permutation procedure (MRPP). As the name suggests MRPP is a class of multivariate permutation for testing the hypothesis of no difference between two or more groups (Zimmerman et al., 1985). Although it is similar in its objective to classical t-test and Analysis of Variance but it is comparatively a robust method as it does not depend on the assumptions of normality and homoscedasticity (McCune et al., 2002). All three forest types were considered as three groups and tested for similarity in terms of disturbance variables. Standard Euclidean distance measure was used to compute the test statistics (Jongman et al., 1995; McCune et al., 2002). Both tests were done in using R version 2.14.0 (R Development Core Team, 2011)

Finally, disturbance variables were analysed using Principal Component Analysis (PCA) to examine the degree of segregation of three forest types in terms of their disturbance regimes. Only those principal components with Eigen values greater than one were selected for representation of forest types across different disturbance regimes. Disturbance variables were z-standardized (mean zero and unit standard deviation) before carrying out the MRPP test and PCA so that all variables get equal weight (Jongman et al., 1995; McGarigal et al., 2000).PCA was done using software SPSS version 16 (SPSS, 2007).

3.2.2. Relationship between vegetation structure and disturbances

The relationship between the disturbance variables and vegetation structural variables was explored visually through scatterplots and statistically through Pearson correlation matrix for each forest type using R version 2.14.0 (R Development Core Team, 2011). Among highly correlated disturbance variables, only those with the larger PCA loading value and high variance across sampling units were selected for the subsequent analysis.

Human proximity was quantified from village and road layers in program ARCMAP version 9.3 (ArcGIS, 2008) At each plot, two variables were measured: count of villages within 3 km radius and the total length of trails and roads within 1 km radius. Sampling plots represented two levels of protection; dry and hill forest plots received more protection (part of Rajaji National Park) than most moist forest plots (Dehradun Reserve Forest). Spearman's correlation between disturbance components and human proximity (segregated by forest types), and t-test on disturbance components between protection levels were carried out.

3.2.3. Effect of disturbance on vegetation structure and composition

To assess the impact of disturbance on vegetation structure and composition, Generalized Linear Mixed effect Models (GLMMs) were built. GLMM is an extension of generalized linear model in which the linear predictor contains random effects in addition to the usual fixed effects. It is the preferred choice of analysis when data structure is correlated due to either nested design of the study or due to repeated measurements (Bolker et al., 2009). Also, non normal data can be easily analyzed using this class of mixed effect model (Bolker et al., 2009). Linear and Poisson mixed effect models (Zuur et al., 2009a; Crawley, 2012) with logical alternate combinations of disturbance indicators as fixed effects and random effects of plots were built and compared by Akaike Information Criterion (AIC) using R version 2.14.0 (R Development Core Team, 2011).Tree and shrub species diversity was calculated separately for each point using software PC-ORD version 4.2 (McCune & Mefford, 1999).

L.camara, an exotic invasive plant, is one of the most dominant shrub species in the understory across all forest types of the study area. Due to its strong association with disturbance and its significance in the study area, an analysis was done to find out the disturbance variable(s) responsible for (a) *L.camara* presence and (b) its abundance. Response of *L.camara* to disturbance variables was assessed through conditional modelling approach. It is a two step process, in first step only presence and absence of the response is modeled using logistic regression and in the final step varying levels of abundance is modeled with presence only data using linear models (Welsh et al., 1996; Barry & Welsh, 2002; Fletcher et al., 2005). Best fit logistic model was validated using Receiver Operator Curve (ROC). Based on signal detection theory ROC curve proves as a helpful tool in validation of regression model. The curve is plotted using sensitivity vs. (1-specificity) for varying probability threshold. Performance of the model is checked by observing the area under the ROC curve (AUC). Usually AUC values from 0.5–0.7 indicate low accuracy, values between 0.7–0.9 indicate useful applications and values of >0.9 indicate high accuracy (Pearce & Ferrier, 2000). ROC curve were prepared using software SPSS (SPSS, 2007).

3.3. Results

3.3.1. Vegetation characteristics

The number of trees, stand basal area, tree height, tree height diversity and % canopy cover were comparatively higher in the moist forest than the other two forest types. Cover of native shrub species as well as of *L.camara* was highest in the dry forest. Tree species richness and diversity were highest in the hill forest but shrub richness was maximum in the dry forest (Table 3.1).

Table 3.1.: Vegetation characteristics for the three forest types. Figures indicate mean (± SE) calculated over 10 plots from each forest.

Disturbance Variable	**Dry Forest**	**Hill Forest**	**Moist Forest**
Tree (ha^{-1})	278.14 (14.69)	287.07 (16.08)	406.92 (20.24)
Stand basal area (m^2ha^{-1})	171.51 (10.55)	143 (10.64)	317.21 (10.87)
Tree height (m)	15.18 (0.97)	11.19 (0.57)	20.67 (0.69)
Tree height diversity	1.68 (0.04)	1.68 (0.04)	2.02 (0.05)
Canopy cover (%)	65.39 (2.65)	41.40 (2.72)	87.00 (1.49)
Shrub density (m^2)	1.63 (0.11)	0.21 (0.01)	2.45 (0.24)
Shrub cover (m^2)	2.97 (2.11)	1.18 (1.22)	1.89 (1.48)
Lantana cover (m^2)	5.05 (1.03)	1.99 (0.35)	3.63 (0.54)
Tree richness	3.63 (1.41)	4.18 (1.81)	2.51 (1.22)
Tree diversity	1.02 (0.04)	1.66 (0.05)	0.61 (0.05)
Shrub diversity	1.94 (0.03)	1.44 (0.05)	1.29 (0.04)

3.3.2. Comparison of disturbance regimes among forest types

Three forest types differed significantly in terms of disturbance regimes (Δobs = 56.88, Δexp = 59.33, A = 0.041, p = 0.001). Principal component analysis (PCA) carried out on eight standardized disturbance variables resulted in extraction of two principal components (eigen value more than 1) that collectively explained 73% of the total variation in disturbance variables (Figure 3.1). Lopping and grazing constituted the Principal Component 1 and it accounted for 48.6% of the total variance whereas second component related to wood cutting and explained 24.5% of the total variance. Plotting of the forest types along the two principal component axes indicated that dry and hill forest differ from moist forest on the second axis representing wood cutting.

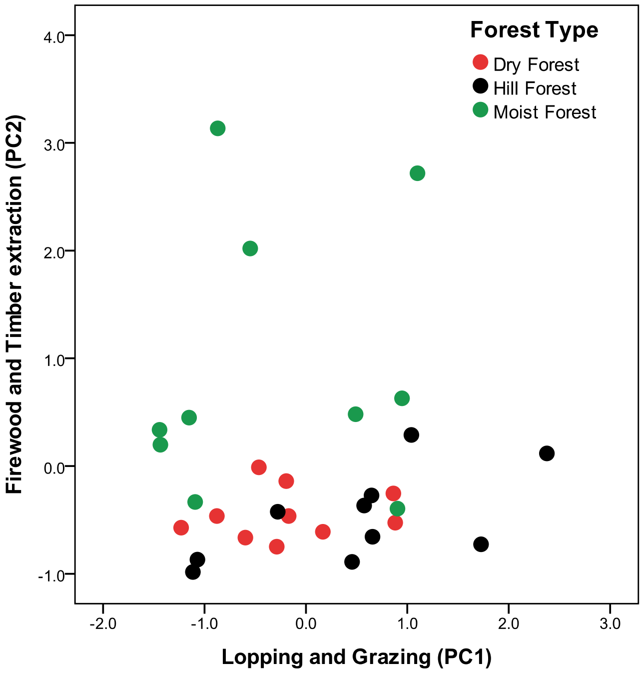
Kruskal-Wallis test between forest types revealed that hill forest had significantly higher percentage of lopped trees and grazing than other two forest types. Dry and hill forests also had higher number of trails. Moist forest had significantly higher firewood collection and timber extraction compared to other two forest types. There were no significant difference among forest types in terms of trail width and number of dung pats (Figure 3.2).

Lopping and grazing intensities were correlated with village density in all forest types (Dry: ρ=0.68, p=0.03; Hill: ρ=0.57, p=0.08; Moist: ρ=0.68, p=0.03). However, firewood and timber extraction were not related to village density except for hill forest (ρ=0.80, p=0.01). Disturbance components were not related to road lengths in any forest type (ρ=0.27–0.49, p 0.15). Firewood and timber extraction was higher (t=2.45, df=8.03, $p<0.05$) in less protected forest plots ($1.03_{Mean} \pm 0.40_{SE}$, n=9) than more protected ones ($0.03_{Mean} \pm 0.02_{SE}$, n=19).

3.3.3. Relationship between vegetation structure and disturbance

In dry forest, canopy cover, native shrub height and shrub cover were negatively related with livestock grazing and firewood collection. However, due to the high correlation between grazing and firewood collection (r = 0.88, p = 0.01), partial correlation was carried out to confirm the relationships. None of the variables showed a significant relationship after partialling out the effect of the other variable (see appendix Table A.1).

Figure 3.1.: Segregation of three forest types on the Principal component axis scores where PC 1 was positively related to lopping and grazing variables whereas PC 2 was positively related with firewood collection and timber extraction.



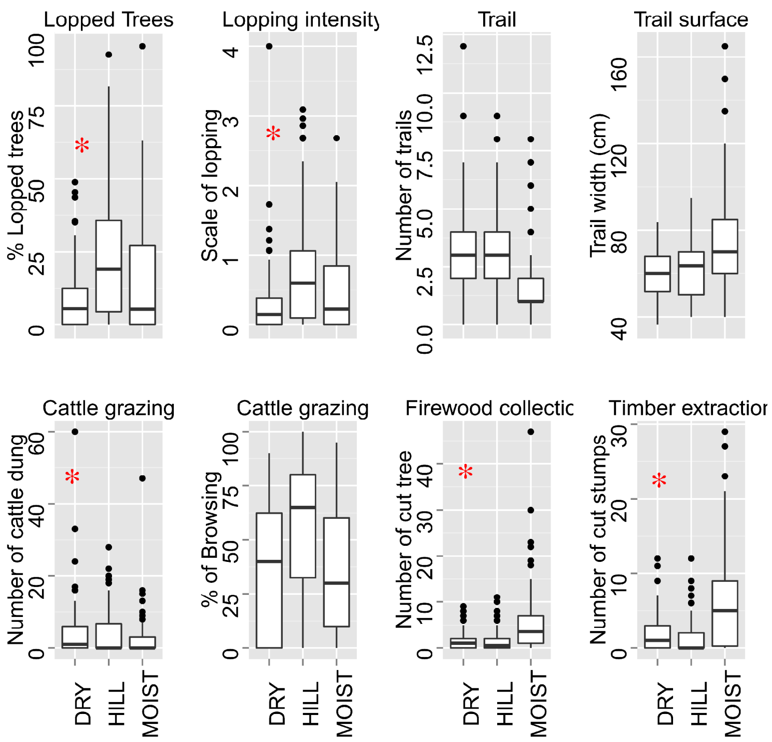
In hill forest, canopy cover and tree crown cover showed significant negative relationship with percent lopped trees and grazing. Partial correlation showed that neither lopping nor grazing was significantly correlated with canopy cover or crown cover. Tree density had a significant positive relationship with timber extraction. Height of native shrubs was negatively related to lopping. *L.camara* cover exhibited a strong positive relationship with lopping and timber extraction Table A.1.

In moist forest, percentage canopy cover showed a significant negative relationship with both percent lopping and grazing. Partial correlation revealed a strong negative relationship between lopping and percentage canopy cover (r = -0.86, p=0.003).

3.3.4. Response of tree layer structure to disturbance indicators

Candidate generalized linear mixed effect models for different attributes of tree layer structure as a function of disturbance variables were compared (Table 3.2). In

Figure 3.2.: Comparison of standardizes mean values (±SE) of disturbance indicators among three forest types through Multiple comparison after Kruskal-Wallis test. Asterisk sign * indicates statistically different mean value at p= 0.01.



dry forest, timber extraction showed weak negative association with basal area and crown cover of trees but tive association with tree density. Livestock grazing and lopping had significant negative effect on canopy cover (Table 3.3). In hill forest, lopping and livestock grazing reduced tree crown cover and canopy cover. Firewood collection and timber extraction was positively associated with tree density (Table 3.3). In moist forest, timber extraction showed negative association with tree basal area and positive association with tree density. Lopping pressure had negative effect on percentage canopy cover and tree crown cover (Table 3.3). Best models were validated by plotting the values of residual vs. fitted where absence of any pattern in the plot indicated the good fit (appendices 3.3 & 3.4).

3.3.5. Response of structure of shrub layer to disturbance

Disturbance variables influencing the height and cover of native and invasive shrubs were different between forest types (Table 3.4). In dry forest, timber extraction reduced native shrub cover and lopping pressure increased *L. camara* cover. Livestock grazing reduced the height of native shrubs but showed positive association with *L. camara* height (Table 3.5). In hill forest, livestock grazing reduced native shrub height and cover. None of the disturbance variables were associated with the height and cover of *L. camara* in hill forest (Table 3.5). In moist forest, lopping, livestock grazing and timber extraction reduced native shrub height, but did not influence *L. camara* height and cover (Table 3.5).

Table 3.2.: Tree structural variables were modeled with logical combinations of potential predictors using generalized linear mixed model. Chi-sq statistics showing comparison with null model keeping plot as random effect. Best model indicated in bold. See table Table 2.1 for keys to variable codes.

Vegetation Structure	**Model description**	**AIC**	**df**	**logLik**	**chi-sq**	**p-value**
		Dry Forest				
Basal Area	perlopp+cuttr+cutst+grz	206	7	-96.08	8.4	0.08
	perlopp+cuttr+cutst	194.3	6	-91.16	8.5	0.04
	cuttr+cutst	184.3	5	-87.18	8.5	0.02
	cutst	**179.3**	**4**	**-85.66**	**6.6**	**0.01**
Crown cover	perlopp+cuttr+cutst+grz	208.6	7	-97.29	6.3	0.17
	cuttr+cutst+grz	199	6	-93.51	6.1	0.10
	cutst+grz	193	5	-91.52	5.4	0.06
	cutst	**182**	**4**	**-87.01**	**4.4**	**0.04**
Tree density	perlopp+cuttr+cutst+grz	167	7	-76.48	5.9	0.21
	cuttr+cutst+grz	156.7	6	-72.33	5.8	0.12
	cuttr+cutst	193	5	-67.46	5.2	0.07
	cutst	**182**	**4**	**-65.09**	**4.6**	**0.03**
Canopy cover	perlopp+cuttr+cutst+grz	785	7	-385.5	22.5	0
	perlopp+cuttr+grz	**784.7**	**6**	**-386.4**	**22.4**	**0**
		Hill Forest				
Basal Area	perlopp+cuttr+cutst+grz	231.3	7	-108.7	4.06	0.39
	perlopp+cuttr+grz	224.3	6	-106.2	4.09	0.25
	perlopp+cuttr	212.9	5	-101.5	3.79	0.15
	perlopp	**206.5**	**4**	**-99.28**	**3.03**	**0.08**
Crown cover	perlopp+cuttr+cutst+grz	229.3	7	-107.7	27.2	0.001
	cuttr+cutst+grz	223.7	6	-105.9	26.2	0.001
	cutst	**218.8**	**4**	**-104.4**	**23.8**	**0.001**
Tree density	perlopp+cuttr+cutst+grz	-429.5	7	221.7	7.23	0.12
	cuttr+cutst+grz	-448.3	6	230.2	7.23	0.07
	cutst	**-467.8**	**5**	**238.9**	**7.24**	**0.03**
Canopy cover	perlopp+cuttr+cutst+grz	815.3	7	-395.4	21.6	0.001
	perlopp+cuttr+grz	815.2	6	-396.4	21.64	0.001
	perlopp+grz	815	5	-397.4	21.3	0.001
		Moist Forest				
Basal Area	perlopp+cuttr+cutst+grz	184.0	7	-85.0	8.0	0.09
	perlopp+cuttr+grz	172.6	6	-80.3	7.9	0.05
	perlopp+cuttr	163.6	5	-76.8	7.2	0.03
	perlopp	**154.8**	**4**	**-73.3**	**4.7**	**0.03**
Crown cover	perlopp+cuttr+cutst+grz	185.1	7	-85.6	15.2	0.004
	perlopp+cuttr+grz	174.7	6	-81.4	14.32	0.003
	perlopp+cuttr	166.1	5	-78.1	13.22	0.001
	perlopp+grz	**158.8**	**5**	**-75.4**	**11**	**0.001**
Tree density	perlopp+cuttr+cutst+grz	-422.5	7	218.3	15.8	0.003
	perlopp+cuttr+grz	-440.5	6	226.2	15.4	0.002
	perlopp	**-455.6**	**5**	**232.8**	**13.6**	**0.001**
Canopy cover	perlopp+cuttr+cutst+grz	11.6	7	1.2	21.6	0.001
	perlopp+cuttr+grz	-0.08	6	-396.4	6.04	0.001
	perlopp+cuttr+grz	-11.8	6	-396.4	10.9	0.001
	perlopp+cuttr+grz	**-23.4**	**4**	**15.7**	**40.4**	**0.001**

Table 3.3.: Parameter estimates of the best models for tree structural variables for all three forest types showing regression coefficient ± SE and t-statistics.

Forest type	**Vegetation structure**	**Lopping**		**Firewood collection**		**Timber extraction**		**Grazing**	
		β±SE	t-value	β± SE	t-value	β± SE	t-value	β± SE	t-value
	Basal area	—	—	—	—	-0.04±0.26	-1.37	—	—
Dry Forest	Crown cover	—	—	—	—	-0.03±0.26	-1.14	—	—
	Tree density	—	—	—	—	-0.02±0.01	-0.83	—	—
	Canopy cover	-0.15±0.29	-0.51	0.45±1.32	0.34 —	—	—	**-0.23±0.11**	**-2.12**
	Basal area	-0.006±0.003	-1.72	—	—	—	—	—	
Hill Forest	Crown cover	**-0.018±0.004**	**-4.26**	—	—			**0.006±0.003**	**-2.01**
	Tree density	—	—	**0.001±0.0006**	**2.31**	0.001±0.0006	0.75	—	—
	Canopy cover	**-0.46±0.12**	**-3.8**	—	—	—	—	-0.16±0.09	-1.68
	Basal area	—	—	—	—	**-0.02±0.01**	**-2.18**	—	—
Moist Forest	Crown cover	**-0.014±0.004**	**-3.39**	—	—	—	—	—	—
	Tree density	**0.001±0.0001**	**-2.19**	—	—	**0.001±0.0003**	**3.03**	—	—
	Canopy cover	**-0.009±0.001**	**-7.79**	—	—	—	—	—	—

Table 3.4.: Shrub structural variables were modeled with logical combinations of potential predictors using GLMM. Best model indicated in bold. See table Table 2.1 for keys to variable codes.

Vegetation Structure	**Model description**	**AIC**	**df**	**logLik**	**chi-sq**	**p-value**
		Dry Forest				
Shrub height	perlopp+cuttr+cutst+grz	109.2	7	-47.51	13.8	0.008
	perlopp+cuttr+grz	101.5	6	-44.78	9.7	0.008
	perlopp+grz	**96.3**	**5**	**-43.13**	**9.8**	**0.07**
Shrub cover	perlopp+cuttr+cutst+grz	264.36	7	-125.2	16.43	0.003
	cuttr+cutst+grz	255.34	6	-121.7	16.4	0.001
	cuttr+cutst	245.94	5	-118	14.6	0.001
	cutst	**243.17**	**4**	**-117.6**	**11.1**	**0.001**
		Hill Forest				
Shrub height	perlopp+cuttr+cutst+grz	107.85	7	-46.92	8.6	0.07
	cuttr+cutst+grz	95.53	6	-41.76	8.4	0.04
	cutst+grz	87.68	5	-38.84	7.7	0.02
	grz	**80.4**	**4**	**-36.2**	**6.2**	**0.01**
Shrub cover	perlopp+cuttr+cutst+grz	287.96	7	-137	8.1	0.09
	perlopp+cutst+grz	281.6	6	-134.8	8	0.05
	perlopp+grz	**275.4**	**5**	**-132.7**	**8**	**0.02**
		Moist Forest				
Shrub height	perlopp+cuttr+cutst+grz	80.8	7	-33.4	23.5	0
	perlopp+cutst+grz	**72.6**	**6**	**-30.28**	**20.6**	**0**
Shrub cover	perlopp+cuttr+cutst+grz	216.7	7	-101.4	21.5	0
	perlopp+cuttr+cutst	206.0	6	-97.02	21.2	0
	cuttr+cutst	**196.3**	**5**	**-93.17**	**20**	**0**

Table 3.5.: Parameter estimates of the best models for shrub structural variables for all three forest types showing regression coefficient ± SE and t-statistics.

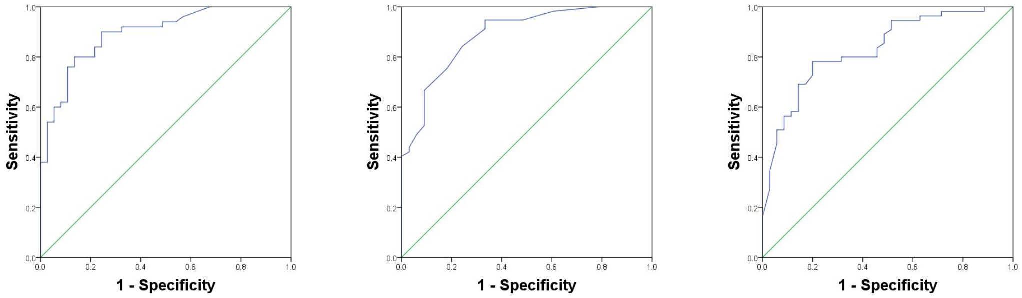
Forest type	**Shrub structure**	**Lopping**		**Firewood collection**		**Timber extraction**		**Grazing**	
		β±SE	t-value	β± SE	t-value	β± SE	t-value	β± SE	t-value
Dry Forest	Shrub height	0.008±0.004	1.82	—	—	—	—	**-0.005±0.002**	**-3.09**
	Shrub cover	—	—	—	—	**-0.09±0.03**	**-2.56**	—	—
Hill Forest	Shrub height	—	—	—	—	—	-0.004±0.001	-2.51	
	Shrub cover	—	—	—	—	—	—	**-0.02±0.01**	**-3.09**
Moist Forest	Shrub height	**-0.05±0.002**	**-2.14**	—	—	**-0.01±0.005**	**-2.09**	**-0.005±0.002**	**-2.67**
	Shrub cover	—	—	**-0.04±0.01**	**-3.72**	**-0.03±0.01**	**-2.95**	—	—

3.3.6. Response of *Lantana camara*, an exotic invasive shrub, to disturbance

Results indicate that timber extraction is responsible for *L.camara* presence in both dry and hill forest (Table 3.6). Validation of logistic regression model through receiver operator curve (ROC; Figure 3.3) shows that the best fit model have high predictive accuracy for all forest types (dry: AUC=0.895; hill: AUC=0.888 and moist: AUC=0.832).

Although the best model for *L.camara* presence in moist forest also had only timber extraction as explanatory variable but it had a negative relationship with *L.camara* presence (Table 3.6). Further, generalized linear modelling with *L.camara* abundance, from presence only observations, revealed that in dry and hill forest it was related to small-extractive disturbances however none of the explanatory variable could explain its abundance in moist forest. In dry forest, *L.camara* abundance decreased with increasing timber extraction and firewood collection but increased with grazing. In hill forest, *L.camara* abundance increased with increasing lopping (Table 3.6).

Figure 3.3.: Receiver operator curve (ROC) curve of best fit model (logistic regression) predicting presence vs absence of *L.camara* for (A) Dry (B) Hill and (C) Moist forest.



(a) Dry forest (b) Hill forest (c) Moistforest

3.3.7. Response of plant diversity to disturbance

Candidate GLMMs for vegetation diversity as a function of disturbance variables were compared (Table 3.7). In dry forest, I did not find effect of any disturbance variable on either tree richness or diversity. On the contrary, timber extraction increased overall shrub diversity (Table 3.8). In hill forest, tree richness increase with lopping. Overall shrub richness decreased with increasing timber extraction

Table 3.6.: Parameter estimates and standard error of the coefficients for the best model for modelling *L.camara* (a) presence using logistic regression and (b) its abundance through linear mixed effect model. Predictors show the variable selected in the best fit model and N shows number of observations.

Forest type	**Logistics Regression**					**Linear mixed model**				
	Predictors	β	SE	z-value	N	Predictors	β	SE	z-value	N
						Firewood collection	**-0.32**	**0.14**	**-2.23**	
Dry Forest	Timber extraction	0.28	0.16	1.79	87	Timber extraction	-0.17	0.08	-1.89	49
						Grazing	0.02	0.01	1.71	
Hill Forest	Timber extraction	**0.71**	**0.31**	**2.28**	90	Lopping	**0.03**	**0.01**	**2.13**	49
Moist Forest	Timber extraction	**-0.13**	**0.05**	**-2.69**	90	None	—	—	—	56

but increased with increasing grazing. Lopping and timber extraction resulted in reduced overall shrub diversity, conversely grazing increased it (Table 3.8). In moist forest, variation in vegetation diversity was not explained by any of the disturbance variables (Table 3.8).

Table 3.7.: Tree and shrub composition variables in all forests were modeled with logical combinations of potential predictors using generalized linear mixed model.Chi-sq statistics showing comparison with null model keeping plot as random effect. Best model indicated in bold.

Vegetation Structure	Model description	AIC	df	logLik	chi-sq	p-value
Dry Forest						
Tree richness	perlopp+cuttr+cutst+grz	55.48	6	-21.93	3.2	0.52
	perlopp+cuttr+cutst	53.48	5	-21.93	3.2	0.36
	perlopp+cutst	51.48	4	-21.98	3.1	0.21
	perlopp	**49.73**	**3**	**-22.15**	**2.8**	**0.09**
Tree diversity	perlopp+cuttr+cutst+grz	134.9	7	-60.46	3.7	0.45
	perlopp+cuttr+cutst	122.3	6	-55.1	3.6	0.31
	perolpp+cutst	114.7	5	-52.4	3.6	0.16
	perlopp	**106.5**	**4**	**-49.29**	**3.3**	**0.1**
Shrub richness	perlopp+cuttr+cutst+grz	59.85	6	-23.93	5.4	0.2
	cuttr+cutst+grz	57.8	5	-23.94	5.4	0.15
	cuttr+cutst	**56.4**	**4**	**-24.2**	**4.87**	**0.08**
Shrub diversity	perlopp+cuttr+cutst+grz	69	7	-27.54	8.29	0.08
	cuttr+cutst+grz	57.8	5	-23.94	5.4	0.15
	perlopp+cuttr+grz	**44.3**	**5**	**-17.17**	**8**	**0.02**
Hill Forest						
Tree richness	perlopp+cuttr+cutst+grz	69.44	6	-28.72	4.8	0.31
	perlopp+cutst+grz	67.47	5	-28.74	4.7	0.19
	perlopp+cutst	66.25	4	-29.13	4	0.14
	perlopp	**65.02**	**3**	**-29.51**	**3.2**	**0.07**
Tree diversity	perlopp+cuttr+cutst+grz	153.5	7	-69.74	5.6	0.23
	perlopp+cutst+grz	145.6	6	-66.8	5.5	0.13
	perlopp+cutst	133.93	5	-61.97	4.6	0.10
	cutst	**123.96**	**4**	**-57.98**	**2.3**	**0.13**
Shrub richness	perlopp+cuttr+cutst+grz	81.11	6	-34.6	11.32	0.02
	perlopp+cutst+grz	79.2	5	-34.6	11.2	0.01
	cutst +grz	**-79.34**	**5**	**-35.67**	**9.1**	**0.01**
Shrub diversity	perlopp+cuttr+cutst+grz	126.38	7	-56.19	11.1	0.03
	perlopp+cutst+grz	**-118.16**	**6**	**-53.08**	**11.0**	**0.01**
Moist Forest						
Tree richness	perlopp+cuttr+cutst+grz	49.9	6	-18.9	3.8	0.43
	cuttr+cutst+grz	47.97	5	-18.9	3.73	0.29
	cutst+grz	46.77	4	-19.39	2.9	0.23
	grz	**45.88**	**3**	**-19.94**	**1.8**	**0.17**
Tree diversity	perlopp+cuttr+cutst+grz	122.67	7	-54.34	1.83	0.76
	perlopp+cuttr+grz	112.53	6	-50.3	1.8	0.61
	cuttr+grz	101.12	5	-45.56	1.8	0.41
	cuttr	**89.27**	**4**	**-40.64**	**1.5**	**0.2**
Shrub richness	perlopp+cuttr+cutst+grz	56.05	6	-22.03	2.4	0.70
	perlopp+cutst+grz	54.05	5	-22.03	2.4	0.48
	perlopp+grz	52.07	4	-22.04	2.4	0.30
	grz	**50.2**	**3**	**-22.11**	**2.27**	**0.13**
Shrub diversity	perlopp+cuttr+cutst+grz	123.1	7	-54.5	4.9	0.29
	perlopp+cuttr+grz	111.3	6	-49.7	4.6	0.18
	perlopp+cuttr+grz	101.7	5	-45.8	4.2	0.12
	perlopp+cuttr+grz	**92.8**	**4**	**-42.4**	**3.4**	**0.06**

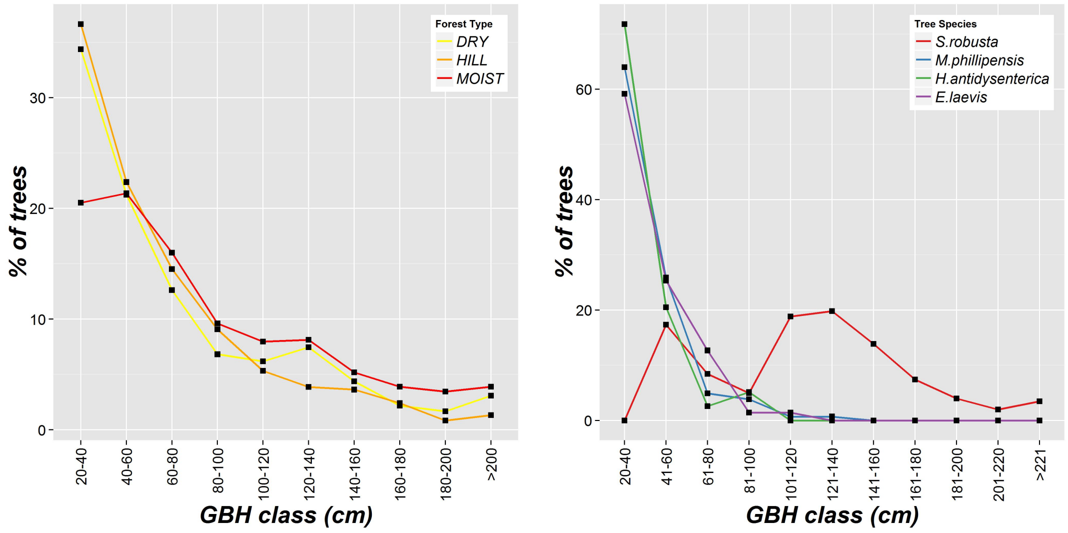
Table 3.8.: Parameter estimates of the best models for vegetation composition for all forest types showing regression coefficient ± SE and t-statistics.

Forest type	Composition	Lopping		Firewood collection		Timber extraction		Grazing	
		β±SE	t-value	β± SE	t-value	β± SE	t-value	β± SE	t-value
Dry Forest	Tree richness	0.009±0.02	0.44	—	—	—	—	—	—
	Tree diversity	0.003±0.005	0.66	—	—	—	—	—	—
	Shrub richness	—	—	0.03±0.02	1.49	0.03±0.01	1.75	—	—
	Shrub diversity	—	—	0.03±0.02	1.62	**0.03±0.01**	**2.68**	—	—
Hill Forest	Tree richness	**0.042±0.02**	**2.15**	—	—	—	—	—	—
	Tree diversity	—	—	—	—	0.03±0.02	1.50	—	—
	Shrub richness	—	—	—	—	**-0.05±0.02**	**-2.64**	**0.004±0.002**	**2.56**
	Shrub diversity	**-0.006±0.002**	**-2.53**	—	—	—	—	0.003±0.002	1.69
Moist Forest	Tree richness	—	—	—	—	—	—	**-0.005±0.003**	**-1.48**
	Tree diversity	—	—	**-0.009±0.007**	**1.20**	—	—	—	—
	Shrub richness	—	—	—	—	—	—	0.003±0.002	1.59
	Shrub diversity	—	—	—	—	—	—	0.003±0.002	-1.85

3.3.8. Tree population structure

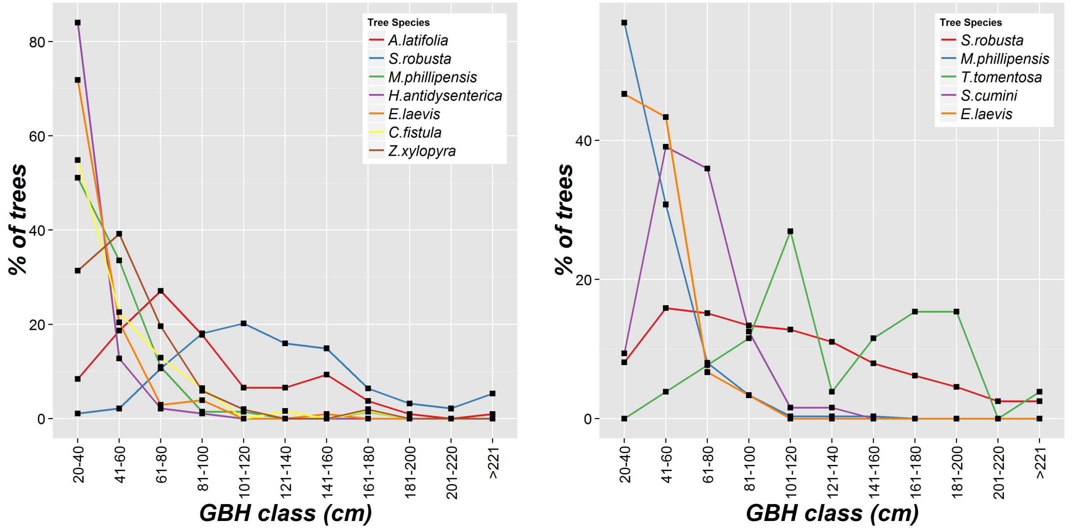
Size class distribution of individuals of tree species in dry and hill forests exhibited the typical reverse J shape or positive skew except moist forest (Figure 3.4 a). However, the size class distribution in moist forest also showed a gradual decrease in tree frequency with increasing GBH class but there was an apparent deficit in the smallest GBH class (20-40 cm) (Figure 3.4 d).

Figure 3.4.: Frequency distribution of trees (all woody plant with GBH >20 cm) compared across forest types and population structure of few dominant tree species within each forest types.



(a) GBH distribution in study area

(b) Dry forest



(c) Hill forest

(d) Moist forest

Percentage tree frequency in only two classes, 20-40 cm and >40 cm, across forest types differed significantly when data was segregated and analyzed between moist and dry forest (χ^2= 45.60, df=1, p<0.0001) as well as between moist and hill forest (χ^2= 62.54, df=1, p<0.0001). Dry and hill forest did not differ (χ^2= 0.81, df=1, p=0.36) in tree frequency for two GBH classes (20-40 & >40 cm) .

Table 3.9.: Number of tree individual in the 20-40 cm GBH classes in all forests were modeled with logical combinations of disturbance variables using generalized linear mixed model. Best model indicated in bold.

Model description	**AIC**	**df**	**logLik**	**p-value**	**ΔAIC**
Dry Forest					
perlopp+cuttr+cutst	**427.21**	**5**	**-208.6**	**0.001**	**0**
perlopp+cutst	**428.28**	**4**	**-210.14**	**0.002**	**1.05**
perlopp+grz+cutst	429.30	5	-209.65	0.003	2.08
perlopp+grz	431.75	4	-211.88	0.009	4.53
cuttr+cutst	432.01	4	-212	0.01	4.79
cutst	433.36	3	-213.68	0.02	6.14
cuttr	436.34	3	-215.17	0.09	9.12
Hill Forest					
perlopp+cutst	**443.63**	**4**	**-217.82**	**0.001**	**0**
perlopp+grz+cutst	**445.23**	**5**	**-217.62**	**0.001**	**1.6**
perolpp+cuttr+cutst	**445.33**	**5**	**-217.66**	**0.001**	**1.69**
cutst	447.88	3	-220.94	0.002	4.24
cuttr+cutst	449.81	4	-220.91	0.009	6.18
perlopp+grz	454.97	4	-223.49	0.123	11.34
cuttr	455.79	3	-224.9	0.224	12.16
Moist Forest					
perlopp+cuttr+cutst	**359.42**	**5**	**-174.71**	**0.001**	**0**
perlopp+cutst	366.24	4	-179.12	0.001	6.82
perlopp+cutst+grz	367.65	5	-178.82	0.003	8.22
perlopp+grz	368.63	4	-180.31	0.004	9.21
cuttr+cutst	370.70	4	-181.35	0.01	11.27
cuttr	371.98	3	-182.99	0.02	12.55
cutst	373.89	3	-183.95	0.05	14.47

I built models to explain observed variation in smallest GBH class within forest types. I expected disturbance variables as the potential reason for this variation therefore, I build models with only disturbance variables as predictors (Table 3.9)

Lopping for fodder collection reduced the number of trees in smallest GBH class unanimously in all three forest types. In turn, timber extraction or removal of big trees increased the number of small trees in dry and hill forests (Table 3.10). In moist forest, firewood collection had a positive relationship with the trees in smallest GBH class. The distribution of abundant tree species within forest types revealed that some species have very low frequency in the smallest GBH classes. Whereas other species exhibited the typical positive skew distribution with highest frequency in the smallest GBH class and gradual decreases in frequency with increasing GBH (Table 3.10). In both dry and hill forests, sal (*Shorea robusta*) had zero individuals in 20-40 cm GBH class and only 8% of the total individual in moist forest. In hill forest, *Anogeissus latifolia* and in moist forest, *Terminalia tomentosa* and *Syzigium cumini* also exhibited a distribution pattern different from the typical reverse J shape. *Mallotus phillipensis* and *Ehretia laevis* two common, understory tree species types showed conformity to the typical inverse J distribution patterns in all forests (Table 3.10).

Table 3.10.: Parameter estimates of the best models for total trees in smallest GBH class for all forest types showing regression coefficient ±SE and t-statistics.

Forest Type	**Lopping**		**Firewood collection**		**Timber extraction**		**Grazing**	
	β±SE	t-value	β± SE	t-value	β± SE	t-value	β± SE	t-value
Dry forest	**-0.025±0.01**	**-2.48**	**0.051±0.02**	**2.34**	**0.070±0.04**	**-1.69**	—	—
Hill forest	**-0.009±0.004**	**-2.38**	**0.077±0.02**	**3.38**	**0.003±0.012**	**-0.23**	0.0004±0.001	0.26
Moist forest	**-0.047±0.014**	**-3.46**	0.021±0.01	1.79	**0.034±0.011**	**3.03**	—	—

3.4. Discussion

3.4.1. Disturbance and forest types

In this study, various disturbances were positively correlated with one another. This is in agreement with other studies on small-scale extractive disturbances. Such high correlation among variables justified the use of PCA for summarizing the disturbance variables (Martorell & Peters, 2005; Karanth et al., 2006). High spatial variability was observed in the intensities of livestock grazing (189% CV of cattle dung and 74% CV of percentage grazed area), firewood collection (180% CV of cut trees), timber extraction (141% CV of cut stumps), fodder collection (122% CV of percentage lopping). Whilst trails were more uniformly distributed (76% CV of trail number and 44% CV of trail width) indicating some forms of human presence throughout the landscape. Results suggested that forest type, human proximity and degree of protection influenced disturbance intensities to some extent. Although village densities explained lopping and grazing disturbance, they barely explained firewood and timber extractions. Moist forest faced manifold high intensity of fire-wood and timber extractions than other forest types. Optimal edaphic conditions and past management practices resulted in well-conditioned Sal trees (straight, tall boles) in the moist forest. Less stringent protection made it easy to harvest them for local agricultural and household needs. Disturbances in dry forest were mostly caused by Gujjar population within Rajaji National Park and villages adjoining the park. That in hill forest was mostly caused by gujjar population inside Rajaji National Park. On the other hand, moist forest was surrounded by towns, villages, and agricultural areas, which were the major source of disturbance.

In this study, preferred fodder species were identified based on literature (Edgaonkar, 1995). Density of preferred fodder species tended to be high in hill ($77.77_{Mean} \pm 19.84_{SE}$) >dry ($34.64_{Mean} \pm 11.81_{SE}$) >moist ($10.25_{Mean} \pm 3.23_{SE}$) forests, and determined lopping pressure across forest types. Thus lopping disturbance was most intensive in hill forest, dominated by *Anogeissus latifolia* and other trees species (*Terminalia tomentosa, Ziziphus xylopyra*, and *Acacia catechu*) preferred by *gujjars* for lopping (Edgaonkar, 1995; Kurien et al., 2007). Contrastingly, moist forest was dominated by Sal (relative abundance 66%), a less palatable tree, and faced less lopping pressure than other forest types. However, due to the low density of other fodder species, local communities lopped Sal (10% of trees were lopped) and *Mallotus phillipensis* (18% trees were lopped), another less palatable species. Kurien et al. (2007) found a similar utilization pattern in eastern part of Rajaji National Park. Species-diverse dry and hill forests (Table 3.1) faced higher lopping and livestock grazing pressures compared to less diverse moist forest with low abundance of fodder tree. Selective lopping of species in dry and hill forests might pose threat to the overall tree diversity in this region. Daniels et al. (1995) observed the disappearance of certain evergreen tree species due to over-utilization in plywood/matchwood industries. In Rajaji National Park, long-term intensive utilization of fodder trees such as *Terminalia belerica* and *Bridelia retusa* had possibly interfered with their regeneration process, leading to their very low numbers (pers.obs.). Declining densities of preferred fodder trees would force the ever-increasing population of gujjars to harvest less palatable species as well.

3.4.2. Extractive disturbances and vegetation structure

Habitat structure plays an important role in providing ecological services such as carbon sequestration and hydrological regulation (Franklin et al., 2002). Simultaneously, it is an excellent surrogate for parameters difficult to quantify (e.g., ecological functions of forests and presence of specialist cryptic animals). Despite being cryptic, extractive disturbances may bring severe changes in habitat structure (Singh et al., 1997; Ramrez-Marcial et al., 2001; Sagar et al., 2003; Kumar & Shahabuddin, 2005) which affects regeneration of native tree and shrub species, ultimately altering vegetation composition (Beckage & Clark, 2003).

In this study, small-scale extractive disturbances were found to affect vegetation structure at both tree and shrub layers, but these relationships differed between forest types. Percentage canopy cover, an important structural variable, responded strongly to lopping pressure. Fodder collection by lopping of over-story trees led to canopy opening in these forests. In dry and hill forest, variation in canopy cover was best explained by both lopping and livestock grazing; whereas in moist forest it was best explained by lopping pressure alone.

Communities involved in lopping were different between forest types. In moist forest, villagers collected fodders for stall feeding their cattle; therefore lopping was not usually associated with livestock grazing. Whilst in dry and hill forest, lopping was largely carried out by gujjars who herded their livestock to the site of lopping resulting in grazing of shrub layer. Such long-term grazing and trampling effects on seedling mortality and poor regeneration (Kuiters & Kirby, 1999; Reimoser et al., 1999; Ramrez-Marcial et al., 2001) could lead to canopy opening. Alternatively, the relationship between canopy cover and grazing could be correlative and not causative, since open canopy areas would support higher understory biomass and attract grazers.

Livestock grazing negatively affected native shrub species, resulting in their stunted growth across forest types. Native shrub cover was also found to be severely affected by small-scale extractive disturbances. Canopy opening and shrub thinning would in turn lead to increased insolation of forest floor, altering soil microclimate (decreased moisture and increased temperature conditions). Increased xeric conditions would be more detrimental for dry than moist forest as very few species would be able to cope with such extreme temperature (Edgaonkar, 1995).

3.4.3. Extractive disturbances and vegetation diversity

Extractive disturbances may reduce competition and release resources, facilitating the colonization of pioneer species (Denslow, 1987). This sometimes leads to an increase in species diversity (Connell, 1978b), but repeated disturbance beyond a threshold can reduce diversity by lowering regeneration and eliminating late successional species (Sagar et al., 2003; Kumar & Shahabuddin, 2005). However, it should be noted that many empirical studies did not find any relationship between disturbance and diversity (see review in (Mackey & Currie, 2001)). Some studies that reported significant relationship did not find enough variation explained. Moreover, forest types can respond differently to disturbances owing to several confounding biotic and abiotic factors (Mackey & Currie, 2001; Bongers et al., 2009) For example, in tropical forest of Ghana (Bongers et al., 2009), disturbance influenced tree species diversity in dry forest more than moist and wet forests. In our study, disturbances influenced native shrub diversity but not tree diversity across forest types. In dry forest, firewood and timber extractions (largely a cumulative effect of past management) had perhaps opened the canopy, releasing resources and facilitating native shrubs. However in hill forest, native shrub diversity decreased with increasing lopping. This might be attributed to more canopy opening and south facing slopes of hill forests that facilitated greater insolation of forest floor, helping light demanding *L.camara* to out-compete native shrubs.

3.4.4. Extractive disturbances and *L.camara* invasion

I identified suites of disturbance variables that explained *L.camara* presence and abundance in different forest types. Canopy opening and fire were responsible for invasion of *L.camara* in dry rainforest of Australia (Gentle & Duggin, 1997). In Shiwalik landscape, timber extraction had the greatest impact on canopy opening and removal of native vegetation. Timber extraction facilitated *L.camara* presence in dry and hill forests but impeded it in moist forest. Sharma & Raghubanshi (2010) showed that areas with canopy cover >63% and moderate soil moisture (7.5-30%) did not face *L.camara* invasion. Even though some areas of moist forest were subjected to timber extraction, the canopy cover was relatively high (76.7-96.5%). The soil-moisture content also likely to be high because of the northern aspect of this forest. Probably due to these reasons, *L.camara* occurrence was relatively low and restricted mostly to the forest edges.

In dry forest, abundance of *L.camara* decreased with increasing firewood and timber extractions. A study from the dry forest of Vindhyan highland revealed that *L.camara* performed well at intermediate shades (Sharma & Raghubanshi, 2010). It was likely that intensive firewood and timber extractions increased xeric conditions and reduced shade availability beyond the optimal level for *L.camara* in dry Shiwalik forest. Removal of palatable vegetation, due to livestock grazing and lopping, might facilitate species adapted to disturbances (Hacker, 1984; Newsome & Noble, 1986; Pettit et al., 1995; Gentle & Duggin, 1997).

Livestock grazing and mechanical soil disturbance reduced native species with partial replacement by exotics in temperate Australian grasslands (McIntyre & Lavorel, 1994). In this study too, livestock grazing in dry forest and lopping in hill forests led to increase in *L.camara* abundance. Such invasion of woody shrub species could lead to gradual modification of structural, compositional and functional characteristics of vegetation communities (Bhatt et al., 1994; Sharma et al., 2005). Increase in *L.camara* cover in Australian Sclerophyll forest led to decrease in native shrub and tree densities (Gooden et al., 2009). Plant species richness in dry rain forest of Queensland decreased with increasing *L.camara* density, and *L.camara* invaded wet Sclerophyll forest of Australia which had fewer plant species than the non-invaded areas (Fensham & Skull, 1999; Gooden et al., 2009). I would also expect the similar change in vegetation composition with ever-increasing *L.camara* densities in the Shiwalik landscape. Therefore, it is important for park managers to prevent / reduce further spread of *L.camara* by managing disturbance activities and early detection and eradication of *L.camara*.

CHAPTER 4

Impact of small-scale extractive disturbances on avian community

4.1. Introduction

Avian assemblages are highly sensitive to changes in the structural and compositional characteristics of their habitat (Raman et al., 1998; Canterbury et al., 2000). Structure of bird community is found to be influenced by the structural complexity of the habitat whereas bird composition is influenced by both vegetation structure and its composition.

Habitat with more vertical layering of vegetation (vertical heterogeneity) in contrast to structurally simple habitat provides more foraging substrate for birds and provides an opportunity for packing up of more species. An increment in bird diversity with increasing foliage height diversity was first established by MacArthur & MacArthur (1961) which was later on confirmed by various studies (MacArthur, 1964; Karr, 1968; Huang et al., 2014). Similarly, among two habitats the one with the increased spatial variability (horizontal heterogeneity) of vegetation, or any resource, should have higher number of species (Wiens, 1974; Roth, 1976; Hovick et al., 2014). In Kibale National Park, Uganda, while studying the lingering influence of past logging activities on bird community, Sekercioglu (2002) observed an increase in bird species richness as well abundance with increasing horizontal heterogeneity of vegetation.

Composition (identity of all species within a community) is an important attribute of bird community and is governed by the structure (old *vs* young forest, open *vs* closed forest) as well as the composition of the vegetation (coniferous vs broad leaved forest). In one of the earliest studies, Rotenberry (1985) established that 55% of the variation in bird composition was related to the vegetation composition (floristic) and rest 35% with vegetation structure (physiognomy) in grassland habitats. Subsequent studies also confirmed the significant association of vegetation composition and bird composition (López & Moro, 1997; Fleishman et al., 2003; Lee & Rotenberry, 2005).

Interestingly, the effect of physiognomy on bird composition was found to be stronger at local scales and vegetation structure at larger scales (Rotenberry, 1985; Fleishman et al., 2003; Jayapal et al., 2009). In dry and moist deciduous forests of central highlands, Jayapal et al. (2009) also found this shift in association between the bird and floristic composition, where it changed from being significant within moist deciduous forest type to non-significant at larger landscape scale. This association of various species with different habitat characteristics makes the bird community sensitive towards modification in their habitat. Therefore any change in the properties of avian habitat could result in modification of bird community structure and composition.

Biomass extraction for firewood and fodder collection, livestock grazing and timber extraction in tropical forests is one of the major causes of habitat modification (Murali et al., 1996; Shankar et al., 1998; Ramrez-Marcial et al., 2001; Tilman & Lehman, 2001; Sagar et al., 2003; Kumar & Shahabuddin, 2005). Apart from direct habitat modification, disturbances often make conditions suitable for native and exotic weedy species to colonize and spread in a disturbed site (Hobbs & Huenneke, 1992; Lodge, 1993; Lozon & MacIsaac, 1997). Invasion and further spread of weedy plant species, particularly the exotic invasives, could also alter the resource availability (Vitousek & Walker, 1989; Witkowski, 1991), disturbance regimes (D'Antonio & Vitousek, 1992; Hiremath et al., 2005) and ecosystem processes leading to habitat modification.

In this chapter, I investigate the attributes of bird community to modified structural and compositional attributes of vegetation, small-scale extractive disturbances and exotic invasive species, *L.camara* in three dominant forest types of Shiwalik landscape. As both the bird composition and their demand for particular resources varies during breeding and non-breeding seasons,I analyzed their response for both seasons. Specifically, I investigated following research questions:

1. How do bird community attributes (richness, density) vary across forest types during breeding and non-breeding season ?

2. Which vegetation (structure and composition) and disturbance variables explain the variation in bird community structural attributes (richness and

density) during breeding and non-breeding seasons ?

3. Does bird community composition change across the disturbance gradient within a forest type and if so which variables (structure and composition of vegetation, disturbance and *L.camara* density) explain it ?

This study was carried out in a contiguous stretch of Shiwalik landscape Three dominant forest types namely dry plain Sal forest (hereafter 'dry forest') in south of the Shiwalik ridge, moist Shiwalik Sal forest (hereafter 'moist forest') in the north–facing slope of Shiwalik ridge and dry Shiwalik Sal forest in the hilly tracts (hereafter 'hill forest') of the ridge (Champion & Seth, 1968) were for the study (Figure 2.1).

A total of 30 sampling grids of 1 km ^{2} were selected across the landscape. Each grid had nine sampling point and at each point, nested circular plots were established for enumerating vegetation characteristics, anthropogenic disturbances and bird community (Figure 2.6). Variable–radius point transect method (Bibby et al., 1992) was used to collect data on bird communities (See chapter 2 for details).

4.2. Data Analysis

4.2.1. Quantifying sampling adequacy and species composition pattern

Sample-based species accumulation curves were generated to determine the adequacy of the sampling effort (Gotelli & Colwell, 2001) across all forest types for both breeding (summer) and non-breeding season (winter). I used hierarchical cluster analysis to examine the degree of dissimilarity in terms of bird composition among forest types during breeding and non-breeding season. Sorenson (Bray-Curtis) distance measure along with flexible beta (β=-0.25) linkage method was used to generate the clusters. To test for statistical difference between the groupings determined by the hierarchical clustering, multi-response permutation procedure (MRPP) was employed. Being a nonparametric multivariate test, MRPP avoids the normality requirements of parametric multivariate tests. MRPP produces a statistic A that describes chance-corrected within-group heterogeneity. A=1 when all samples within groups are identical, A=0 when heterogeneity within groups equals expectation by chance and A <0 when within-group heterogeneity is less than that expected by chance (McCune et al., 2002). Rarefaction curves were produced using software Estimate S (Colwell, 2005) whereas cluster analysis and MRPP test were done using software PC-ORD version 4.20 (McCune & Mefford, 1999).

4.2.2. Estimating bird species richness and densities at intensive sampling points

Bird species richness and densities were estimated from point-transect data for each point within the 1 km^2 grid for breeding (summer) and non-breeding (winter) season.

Since density estimated from raw counts may be highly biased due to differential detectability of species, I corrected for this detection bias in density calculations by fitting a detection function in program DISTANCE (Thomas et al., 2010). Separate detection functions were fitted for each plot and then density for each point was extracted by post-stratification. Appropriate right truncation was used for each group. A detection model was selected after examining the fit of estimated detection function to the data. Model selection was based on minimum Akaike information criteria (AIC). Program PC-ORD version 4.20 was used for estimating the species richness (McCune & Mefford, 1999).

4.2.3. Modelling bird species richness and density as a function of vegetation characteristics and disturbance indicators

The response of bird community to habitat modification due to disturbance was analyzed through mixed effects models, that accounts for the nested sampling design. I selected vegetation and disturbance variables expected to have an influence on the bird species richness and density based on literature survey and field observations (Table 4.1). Many of the explanatory variables were expected to be spatially auto-correlated. Inclusion of highly collinear explanatory variables in the model results in

1. inaccurate model parameterization,
2. decreased statistical power and
3. exclusion of significant predictor during model selection (Graham, 2003).

Therefore, only least or non-correlated variables were considered in the model building. Due to the change in the bird species composition between season and habitat, separate models were built for each forest type for breeding and non-breeding season.

Linear and Poisson mixed effect models (Zuur et al., 2009a; Crawley, 2012) with logical alternate combinations of vegetation, disturbance and *L.camara* as fixed effects and random effects of plots were built and compared by information theoretic approach. Akaike Information Criterion for small sample sizes (AICc) was opted for model selection since the ratio of sample size (n) and number of parameters (K) was small (Burnham & Anderson, 2002). All explanatory variables were z-standardized (with zero mean and unit standard deviation) to make the variables mutually comparable. Analyses were carried out using R version 2.14.0 (R Development Core Team, 2011) with the aid of lme4 package (Bates et al., 2014).

4.2.4. Relationship bird composition and habitat variables

Partial Mantel's test was used to examine the effect of vegetation and disturbance variables on bird species composition across seasons and forests. Since physical proximity among sampling plots could contribute significantly to observed similarities in floral and faunal communities therefore, I partialled out the effect of geographic distance between sampling plots (Legendre & Troussellier, 1988). Distance between two sampling plots was computed from the centre of each plot (1 km^2) in program ARCMAP version 9.3 (ArcGIS, 2008). In partial Mantel's test, relationship among two variables is tested through randomization procedure rather than parametric methods (McCune et al., 2002).

Variables were first converted to similarity matrices that are based on degree of likeness between pairs of sites. In the present analysis bird species composition was the matrix of bird species with their respective abundances totaled from nine intensive sampling points. I used Bray-Curtis distance method for deriving similarity matrices for bird species composition, vegetation structure and composition and other habitat variables. Mantel's test calculates the degree of association between the two distance matrices using simple correlation and test significance of the correlation coefficient by comparing it to values generated by randomizing the matrix many times (999 times, in this case). Analyses were carried out in the R version 2.14.0 (R Development Core Team, 2011) with the aid of package vegan (Oksanen et al., 2011).

Table 4.1.: Description of habitat variable considered a priori to potentially influence bird community attributes, and the rationale for their inclusion in candidate models.

Habitat-characteristic	**Variable**	**Bird-community attribute**	**Rationale**	**References**
Vegetation Structure	Tree crown cover (cv)	Richness,Density	Variety in the foraging substrate will attract different bird species eventually increase richness.	(Daniels et al., 1992)
	Lantana density	Richness,Density	Almost year round availability of food resources and refuge from predators.	(Gosper et al., 2006; Kath et al., 2009; Aravind et al., 2010)
	Tree crown cover	Richness,Density	More resources (i.e., insects, fruits) per unit area will have higher number of individual	(Mills et al., 1991)
	Shrub density	Density	Usually directly influence food resources (mainly insects).	(Kath et al., 2009)
	% canopy cover	Density	Modifies the light availability and visibility of food resources (insects).	(Thiollay, 1999)
Vegetation Composition	Tree diversity	Richness	Different tree species might add to horizontal and vertical heterogeneity therefore more foraging niches	(Daniels et al., 1992; Chettri et al., 2005)
	Shrub diversity	Richness	Modifies the light availability and visibility of food resources and also for predators.	(Thiollay, 1999)
Disturbance	Fire	Richness,Density	It influence bird's choice of an area, bird species richness is expected to be negatively influenced by fire.	(Apfelbaum & Haney, 1981)
	Lopping	Richness,Density	Lopping will reduce the food resources by reducing the leaf cover on trees consequently reduced species richness.	(Chettri et al., 2001; Shahabuddin & Kumar, 2006)
	Timber extraction	Richness,Density	At low level, expected to increase richness by promoting shrub growth (more food and foraging options). But, at high levels, might reduce the potential habitat of forest specialist birds and consequently decline in species richness	(Thiollay, 1997; Sekercioglu, 2002)
	Firewood Collection	Richness,Density	Firewood extraction removes the secondary and tertiary branches as well as leaf biomass from the tree. But could positively influence the weedy and shrub species growth.	(Chettri et al., 2001; Shahabuddin & Kumar, 2006)

4.3. Results

4.3.1. Sampling adequacy and overall pattern of species richness and abundance

Over two years of sampling period, 173 bird species were recorded from the study area. Estimated bird species richness and diversity of each 1 km^2 have been provided in the (appendix Table B.1). Sampling effort sufficiently accounted for the species richness in all three forest types across two seasons (Figure 4.1). Bird species richness and density across all forest types were usually higher during breeding than the non-breeding season (appendices Figure C.1 and Figure D.1). During summer, hill forest had highest bird richness (S_{obs}=111) followed by dry (S_{obs}=103) and moist forest (S_{obs}=96). During winter season all forest types had almost similar species richness (Table 4.2).

Hill forest had the highest bird density compared to other forest types during breeding and non-breeding season. Bird densities were higher during the breeding season than the non-breeding season for all forest types (Table 4.3). Due to incidence of fire in the breeding season some plots in dry and hill forest exhibited lower densities than the non-breeding season (see Figure D.1).

4.3.2. Factors influencing bird community richness and abundance

In dry forest, richness of breeding and non-breeding birds was best explained by coefficient of variance of tree crown cover and *L.camara* density. In non-breeding season, species richness was maximum at medium levels of firewood collection (Table 4.3) Density of both breeding and non-breeding birds was influenced by *L.camara* density and canopy attributes. Timber extraction resulted in decreased bird density during the breeding season but grazing reduced bird density during the non-breeding season (Table 4.5).

In hill forest, breeding and non-breeding species richness was explained by similar sets of vegetation and disturbance variables (Table 4.3). Tree diversity was the additional variable included in the best model during non-breeding season. Areas with fire signs had lower species richness during both breeding and non-breeding season (Table 4.4). During the breeding season, bird density was

Figure 4.1.: Sample based species accumulation curve for three forest types using point transect survey for summer and winter season.

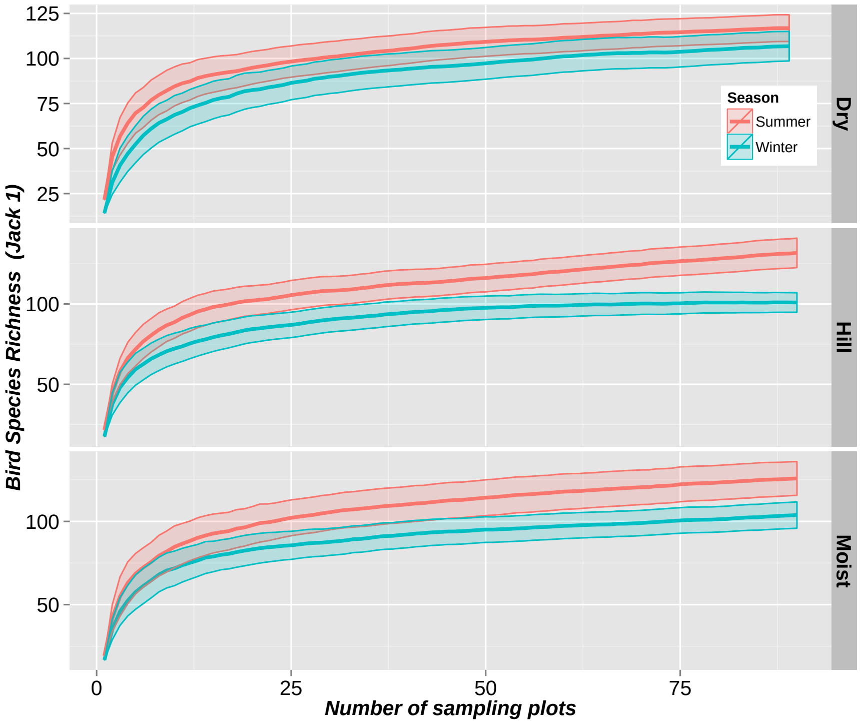


Table 4.2.: Nonparametric species richness estimates from point count surveys for all three forest types covering two seasons.

	Breeding			Non-breeding		
	Dry	Hill	Moist	Dry	Hill	Moist
S_{obs}	103	111	96	90	90	89
N_{obs}	3952	4254	4294	2389	2554	2947
Chao1	110.3 (0.93)	124.9 (0.89)	111.8 (0.86)	111.3 (0.80)	95 (0.95)	108.5 (0.82)
Jack1	117.8 (0.87)	131.7 (0.84)	123.6 (0.78)	106.8 (0.84)	100 (0.89)	103.8 (0.86)
Species diversity H’	3.70	3.72	3.73	3.57	3.68	3.43
Density	44.5 (6.06)	48.5 (9.3)	41.5 (6.47)	27.1 (7.46)	35.2 (7.56)	27.6 (9.37)

best explained by firewood collection and *L.camara* density. Firewood collection had a negative influence on bird density during the breeding season. In the non-breeding season, shrub density, tree crown cover and *L.camara* density influenced bird density (Table 4.4). However predictor variables estimated by the best model had weak effect sizes and zero-spanning confidence intervals during the non-breeding season (Table 4.6).

In moist forest also, *L.camara* density was an important variable that positively influenced both breeding and non-breeding species richness (Table 4.3). Firewood collection and percentage canopy cover negatively influenced the breeding bird richness. In the non-breeding season, species richness decreased with timber extraction but increased with lopping (Table 4.4). During both breeding and non-breeding seasons, combination of disturbance and *L.camara* density were the principal factors explaining the bird density patterns. In the breeding season, *L.camara* density and firewood collection significantly influenced bird density. However, the best model selected in the non-breeding season had low fixed effect sizes with zero-spanning confidence intervals (Table 4.6).

Figure 4.2.: Dendrogram showing clustering of plots on the basis of bird species composition within three forest types for (a) breeding and (b) non-breeding season. Plots from similar forest are identically colour coded, red=dry, green=hill and blue=moist forest.

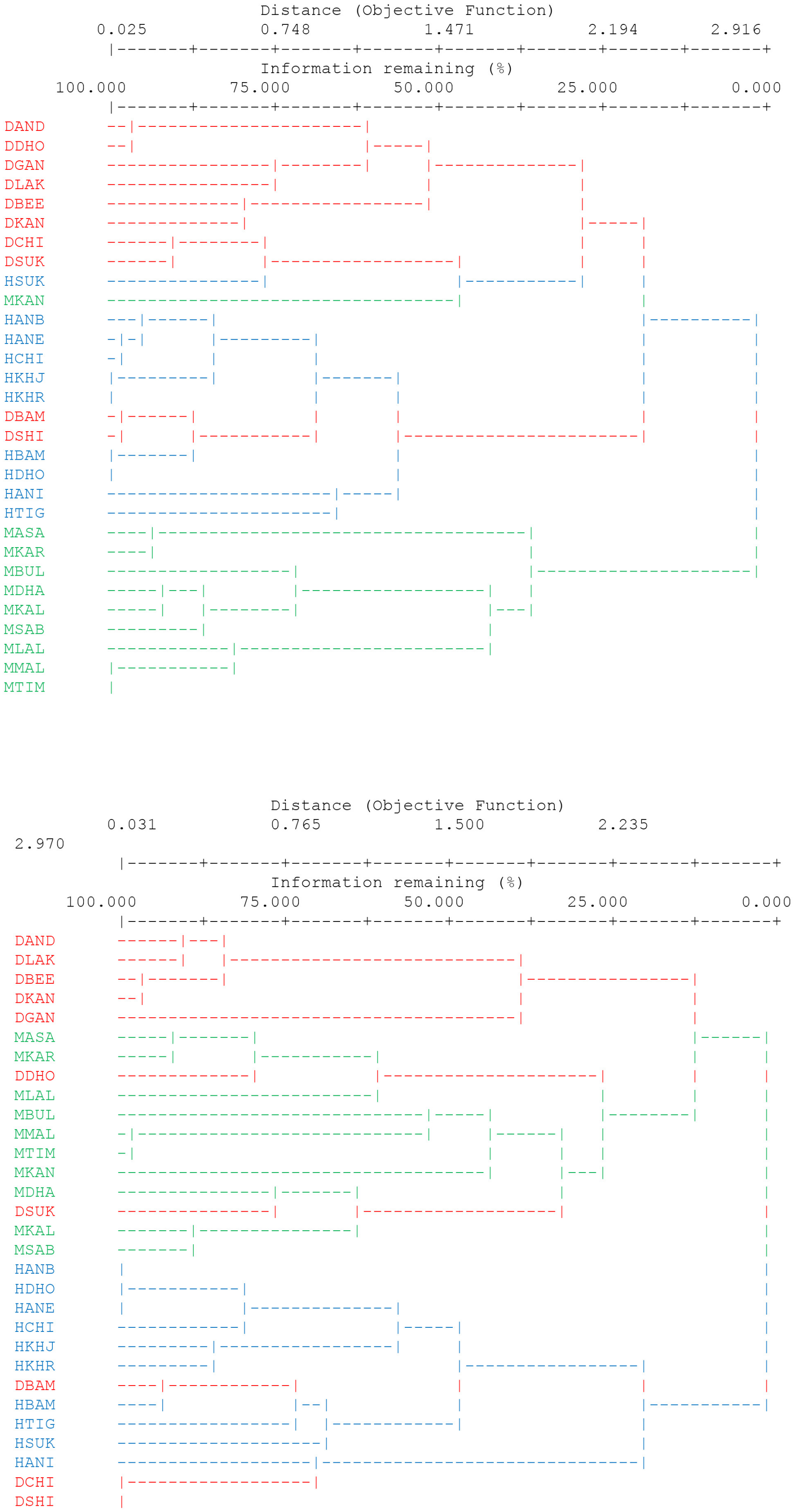


Table 4.3.: Summary statistics [Model description , Akaike Information Criteria (AICc), relative support for hypothesis (Δ AICc), degrees of freedom (df), significance (p-value) of deviance, of candidate models explaining **Bird Species Richness** as a function of vegetation, disturbance and invasive cover during (a) breeding and (b) non-breeding season of 2009–11.

Forest Type	**Model description**	**AIC**	**Δ AICc**	**df**	**chi-sq**	**p-value**
	Breeding season					
Dry Forest	CV of tree crown cover +shrub density +lantana density	110.58	0.00	4	14.97	0.002
	Native shrub density +lantana density	113.20	2.50	3	10.11	0.005
	Lantana density	113.20	2.62	4	8.03	0.005
	CV of tree crown cover	116.92	6.34	3	4.19	0.041
	Shrub diversity +Tree diversity	123.27	12.69	5	0.04	0.981
Hill Forest	Lantana density +% canopy cover +fire	98.18	0.00	5	11.25	0.010
	Lantana density	99.90	1.72	3	5.10	0.024
	Fire	101.54	3.36	3	3.47	0.063
	Lantana density +shrub density	102.03	3.85	4	5.16	0.076
	CV of tree crown cover +%canopy cover	104.29	6.11	4	2.91	0.233
	Tree diversity + Shrub diversity	105.92	7.74	4	1.27	0.529
Moist Forest	Fire wood collection + Lantana density + % canopy cover	119.32	0.00	5	31.90	0.000
	CV of tree crown cover +% canopy cover	128.59	9.27	4	20.38	0.000
	Firewood collection + Lopping	130.48	11.16	3	18.50	0.000
	Lantana density +Shrub density	130.78	11.46	4	18.19	0.000
	Shrub diversity	135.21	15.89	3	0.06	0.804
	Lantana density	136.22	16.90	3	10.56	0.001
	Non-breeding season					
Dry Forest	CV of tree crown cover +shrub diversity +Lantana density +firewood collection+ I(firewood collection^2)	155.57	0.00	7	24.24	0.000
	CV of tree crown cover	168.45	12.88	3	2.26	0.133
	Lantana density	164.23	8.66	3	6.48	0.011
	Shrub density+ Lantana density	161.21	5.64	4	11.70	0.003
	Shrub diversity + Tree diversity	164.30	8.72	4	8.61	0.014
	Firewood collection +I(firewood collection^2)	164.73	9.15	4	8.18	0.017
Hill Forest	Lantana density +Tree diversity+ fire	135.92	0.00	5	11.99	0.007
	Lantana density	137.40	1.48	3	7.22	0.007
	Lantana density +Shrub density	138.38	2.46	4	8.43	0.015
	% canopy cover +CV of tree crown cover	140.04	4.12	4	6.77	0.034
	Fire + Lopping	142.23	6.31	3	4.29	0.117
	Tree diversity	142.53	6.61	4	1.65	0.199
Moist Forest	Lopping +Timber extraction + Tree crown cover	120.13	0.00	5	20.48	0.000
	Lopping + Timber extraction	122.79	2.66	4	14.47	0.001
	% canopy cover+ Tree crown cover	127.22	7.09	4	10.03	0.007
	Lantana density	130.63	10.51	3	4.42	0.035
	Lantana density+ Shrub density	132.04	11.92	4	5.21	0.074
	Shrub diversity	134.74	14.61	3	0.31	0.575

Table 4.4.: Summary statistics [Model description, Akaike Information Criteria (AICc), relative support for hypothesis (ΔAICc), degrees of freedom (df), significance (p-value) of deviance, of candidate models explaining **Bird Species Richness** as a function of vegetation, disturbance and invasive cover during (a) breeding and (b) non-breeding season of 2009–11.

Forest Type	**Predictors**	β	**SE**	**z-value**	**Correlation coeffcient**
	Breeding season				
	CV of tree crown cover	0.06	0.02	2.25	
Dry Forest	Lantana density	0.08	0.03	2.86	**0.73**
	Shrub density	-0.06	0.03	-1.81	
	Fire	-0.12	0.07	-1.81	
Hill Forest	Lantana density	0.07	0.03	2.37	**0.62**
	% canopy cover	0.04	0.03	1.56	
	% canopy cover	-0.09	0.03	-3.44	
Moist Forest	Lantana density	0.06	0.03	2.28	
	Firewood collection	-0.10	0.04	-2.66	**0.73**
	CV tree crown cover	0.06	0.03	2.08	
	Shrub diversity	0.10	0.03	2.96	
	Non-breeding season				
Dry Forest	Lantana density	0.07	0.03	2.44	**0.46**
	Firewood collection	-0.14	0.06	-2.15	
	Firewood collection	0.06	0.02	2.34	
	Fire	-0.12	0.08	-1.49	
Hill Forest	Lantana density	0.10	0.03	3.29	**0.57**
	Tree diversity	0.06	0.03	1.90	
	Lopping	0.12	0.03	3.52	
Moist Forest	Tree crown cover	0.07	0.03	2.29	**0.75**
	Timber extraction	-0.06	0.03	-1.88	

Table 4.5.: Summary statistics [Akaike Information Criteria (AICc), relative support for hypothesis (ΔAICc), degrees of freedom (df), significance (p-value) of deviance, of candidate models explaining **Bird Density** as a function of vegetation, disturbance and invasive cover during (a) breeding and (b) non-breeding season of 2009–11.

Forest Type	**Model description**	**AIC**	**Δ AICc**	**df**	**chi-sq**	**p-value**
	Breeding season					
Dry Forest	CV of tree crown cover + Lantana density+ Timber extraction+ I(Timber extrcation^2)	286.19	0.00	7	22.65	0.000
	Lantana density	290.50	4.31	4	4.05	0.044
	Timber extraction + I(Timber extraction^2)	293.10	6.91	5	8.96	0.011
	Tree crown cover+ shrub cover + Lantana density	304.15	17.96	6	0.98	0.806
Hill Forest	% canopy cover	308.05	0.00	4	1.59	0.208
	Lantana density	309.27	1.23	4	0.13	0.717
	Firewood collection + I(Firewood collection^2)	310.45	2.40	5	4.52	0.104
	Shrub density + Tree crown cover + Lantana density	316.41	8.37	6	1.51	0.680
Moist Forest	Lantana cover + I(Lopping^2)	308.28	0.00	5	20.22	0.000
	I(Lopping^2)	311.76	3.48	4	14.49	0.000
	Tree crown cover + Shrub density + Lantana density	313.87	5.59	6	15.31	0.002
	Lantana density	317.74	9.46	4	7.04	0.008
	% canopy cover	318.92	10.64	4	5.61	0.018
	% canopy cover+ Lantana cover + Grazing	341.37	0.00	7	19.12	0.001
	% canopy cover	342.59	1.22	4	8.54	0.003
	Non-breeding season					
Dry Forest	Fire + I(Timber extraction^2)+ Grazing	344.31	2.94	6	14.66	0.002
	Lantana density	348.04	6.67	4	3.33	0.068
	Tree crown cover + Shrub density+ Lantana density	352.61	11.24	6	6.44	0.092
Hill Forest	Shrub density+ Tree crown cover	358.78	0.00	5	3.94	0.140
	Lantana density	358.89	0.12	4	0.03	0.855
	Firewood collection + I(Firewood collection^2)+Lopping	366.60	7.82	6	0.52	0.914
	% canopy cover	369.56	10.78	5	0.91	0.634
Moist Forest	Lopping + Fire	321.64	0.00	5	4.71	0.01
	Lantana cover	323.42	1.78	4	1.08	0.299
	% canopy cover	324.32	2.68	4	0.02	0.877
	Tree crown cover + Shrub density + Lantana density	330.35	8.71	6	2.22	0.528

Table 4.6.: Summary statistics [Model description, Akaike Information Criteria (AICc), relative support for hypothesis (ΔAICc), degrees of freedom (df), significance (p-value) of deviance, of candidate models explaining **Bird Density** as a function of vegetation, disturbance and invasive cover during (a) breeding and (b) non-breeding season of 2009–11.

Forest Type	**Predictors**	β	**SE**	**z-value**	**Correlation coefficient**
	Breeding season				
Dry Forest	CV of tree crown cover	0.25	0.10	2.43	
	Timber extraction	-0.66	0.17	-3.77	0.94
	I(Timber extraction^2)	0.20	0.07	2.75	
	Lantana density	0.82	0.27	3.01	
Hill Forest	Firewood collection	-0.46	0.24	1.91	
	I(Firewood collection^2)	0.20	0.10	2.07	0.76
	Lantana density	0.04	0.17	0.22	
Moist Forest	Lantana density	0.32	0.14	2.36	0.84
	I(Firewood collection^2)	0.21	0.06	3.28	
	Non-breeding season				
Dry Forest	Grazing	0.52	0.22	2.42	
	Lantana density	0.41	0.20	2.09	0.84
	% canopy cover	-0.55	0.22	2.47	
Hill Forest	Lantana density	-0.09	0.23	0.40	0.53
	Shrub cover	-0.33	0.20	1.70	
	Tree crown cover	0.20	0.21	0.97	
Moist Forest	Fire	0.51	0.35	1.45	
	Lantana density	0.16	0.16	1.01	0.74
	Lopping	0.34	0.22	1.55	

4.3.3. Relationship between bird community composition and habitat variables

Partial Mantel's test for relationship among bird composition and habitat variables while partialling out the effect of physical distance, indicated significance of different variables across forest types. In dry forest, *L.camara* has a significant relationship with bird composition irrespective of the seasons. In hill forest, average girth of trees had a strong association with bird species composition only during the breeding season. In moist forest, firewood collection showed a significant relationship with bird species composition (Table 4.7).

Table 4.7.: Within habitat association among bird species composition, vegetation (structure and composition) and disturbance as shown by partial Mantel's test across forest types. All habitat variables were contrasted with bird species composition across seasons while partialling out the physical distance. Table shows Mantel's r with its significance value within brackets. Significant relationships indicated in bold.

Habitat Variables	**Dry Forest**		**Hill Forest**		**Moist Forest**	
	Breeding	Non-breeding	Breeding	Non-breeding	Breeding	Non-breeding
Vegetation structure	0.11 (0.33)	0.10 (0.30)	0.22 (0.14)	0.04 (0.41)	-0.12 (0.66)	0.27 (0.17)
Vegetation composition	-0.28 (0.92)	-0.25 (0.89)	-0.11 (0.69)	-0.18 (0.86)	0.16 (0.15)	-0.11 (0.71)
Overall disturbance	0.05 (0.45)	0.05 (0.39)	0.05 (0.38)	-0.08 (0.67)	0.01 (0.44)	-0.05 (0.57)
GBH	-0.04 (0.43)	0.03 (0.45)	**0.46 (0.02)**	0.03 (0.43)	-0.06 (0.60)	0.13 (0.26)
% canopy cover	0.30 (0.12)	0.29 (0.14)	-0.02 (0.52)	-0.01 (0.51)	-0.04 (0.51)	0.27 (0.14)
Lantana density	**0.70 (0.01)**	**0.69 (0.01)**	-0.02 (0.55)	-0.01 (0.52)	0.03 (0.39)	0.13 (0.27)
Lopping	**0.32 (0.05)**	0.30 (0.06)	0.27 (0.17)	-0.15 (0.80)	-0.02 (0.50)	0.06 (0.30)
Firewood	**0.89 (0.01)**	**0.90 (0.01)**	-0.11 (0.65)	0.08 (0.31)	**0.34 (0.03)**	-0.11 (0.71)
Grazing	0.01 (0.37)	0.10 (0.40)	0.40 (0.09)	-0.07 (0.60)	-0.06 (0.57)	0.16 (0.23)
Timber	**0.88 (0.01)**	**0.90(0.01)**	-0.26 (0.88)	0.11 (0.24)	-0.13 (0.71)	-0.32 (0.92)

4.4. Discussion

4.4.1. Species richness and abundance across disturbance gradient

Breeding season densities in forests are generally higher than winter densities, although the magnitude of the difference varies with forest type. Seasonal changes in avifauna of temperate forests are more extreme than changes in avifauna of tropical forests (Karr, 1976b). Similar trends were observed in recent studies conducted on bird communities in similar habitats (Mohan, 2007; Kumar, 2011). In our study also, species richness and density were higher during the breeding season compared to non-breeding season. At plot level, neither species richness nor density showed any pattern across a disturbance gradient in any of the forest type (see appendices Figure C.1 and Figure D.1). This could be attributed to the variation due to inherent properties of the sampling points which was being masked on averaging the response and predictors at plot level.

4.4.2. Factors affecting overall bird species richness

Invasive species cover *(L. camara* density) had a greater influence on bird richness irrespective of the season. All the forest types in this study area do not contain many fruit producing tree and shrubs, especially the Sal dominated moist and dry forest. These forest are usually dominated by insectivorous birds (61% in this study) and increased availability of food resources (fruit and seed) could attracts a great variety of frugivorous and omnivorus bird species in *L. camara* invaded areas thus elevating the richness (Turner & Downey, 2008; Aravind et al., 2010). Low (1999) has also mentioned that *L. camara* is a keystone resource for many small passerines because of the dense cover and food resource it provides. A study conducted in Australia found that *L. camara* was the important food material for more than 50% of the bird species. Another study from Australia, revealed a positive relationship between *L. camara* and bird richness and abundance (Kath et al., 2009). *L. camara* modifies not only the food resources of the native habitat but it also alters vegetation structure by its thicket forming nature which smothers the native plant communities (Sharma et al., 2006). It forms dense, impenetrable thickets adorned with curved thorns. All these characteristics might prove beneficial for providing safe nesting opportunities to the birds especially during the breeding season.

Even during the non-breeding season when the resources are at their low, *L. camara* could act as a key food resource to the migrant and resident bird community. Some of the migratory birds switch to frugivory in their wintering grounds especially consuming the small sized (i.e., *L.camara*) fruits suited to their small beaks (Martin, 1985). However, these positive influences of *L.camara* on native bird species richness need further inquiry since it is mostly the generalist species like bulbuls, white-eye,starlings and babblers which are benefitted.

Coefficient of variation of tree crown cover, an index of canopy patchiness, was another important variable positively influencing bird species richness during breeding season. Micro-spatial heterogeneity plays an important role in regulating the community diversity (Pianka, 1966). MacArthur & MacArthur (1961) established significance of within plot patchiness (foliage height diversity) as an important variable for packing of more species in a habitat. However, Roth (1976), Murdoch et al. (1972) and Wiens (1974) attempted to measure and relate horizontal component of habitat diversity with faunal community. In another study from India, Daniels et al. (1992), used coefficient of variance of canopy cover as an index of horizontal heterogeneity and found a significant positive relationship of it with bird species richness in contrast to vertical heterogeneity.

Fire reduced bird species richness only in the hill forest. Ground cover of hill forest is dominated by grasses which become very dry by the onset of breeding season and makes this forest more fire prone than other forest types. Immediate effects of fire during breeding season include reduction in food resources and potential nesting sites especially for ground dwelling species and increase in predation pressure due removal of vegetation cover (Lawrence, 1966; Komarek, 1969; Best, 1979). All these effects are expected to influence bird species richness similarly in the hill forest and result in decreased richness.

Small-scale extractive disturbance in form of firewood collection and lopping also affected the bird species richness significantly. High amount of wood removal reduced bird species richness across seasons. Being Sal dominated, these forest type harbors a great diversity of insectivorous birds, belonging to leaf and bark gleaners (e.g., woodpeckers, nuthatches,tits, treecreepers) foraging guild. Firewood collection removes the dry wood from the forest floor as well as the terminal branches of the middle and upper story trees and therefore reduced the overall food and nesting resources. This finding is in consensus with a study by Vijayan et al. (2006) in Western Ghats where species richness and nest abundance decreased with increasing disturbance of grazing and firewood collection.

Canopy opening due to fodder or firewood removal has been shown to enhance the bird species richness by attracting generalist birds to the area (Chettri et al., 2001).It has been seen that insects concentrate more near the patches of sunlight and additionally, canopy opening increases the prey visibility against the dark backdrop of forest. In a Bornean rain forest both foraging attack rates and attack successes were higher in the sun patches than in the shaded territories (Orr, 2004). Similarly, lopping and low level of firewood removal during the winter (non-breeding season) elevated the bird species richness in moist and dry forest respectively.

4.4.3. Factors affecting overall bird density

Bird density increased unanimously with increasing *L. camara* density in all forest types across seasons. Moreover, moderate level of disturbance also led to density enhancement among all forest types. Abundance of resources is in terms of food (Mills et al., 1991), nesting (Grewal et al., 1987; Newton, 1994) and perch sites (Dickson et al., 1983; Preston, 1990) have been shown as some of the most important predictors of bird density. Therefore, increased resource availability due to year round production of flowers and fruits by *L. camara* as well as increased nesting options might have resulted in increased overall bird density.

In this study, moderate levels of firewood collection and timber extraction resulted in increased overall bird density. Various studies have shown that low extraction of vegetation often results in canopy opening in the otherwise closed forest (Chettri et al., 2002; Shahabuddin & Kumar, 2006). Also, moderately disturbed areas are characterized by higher levels of primary productivity, and consequently vegetative structural complexity, increased insect visibility and fleshy fruit production (Blake & Hoppes, 1986; Levey, 1988; Orr, 2004). Such areas may attract breeding birds by providing better foraging and nesting habitat (Blake & Hoppes, 1986; Noss, 1991), and may be especially important for fledglings from adjacent mature-forest habitats (Anders et al., 1998).

Food resources are at their lowest level in the tropical forest during non-breeding season (Poulin et al., 1992; Norris et al., 2004) which results in increased movement of resident as well as migrant birds and often involves mixed species flock formation for tracking of resources (Develey & Peres, 2000). Birds become extremely nomadic and do not defend territories and hardly restrict themselves to one particular forest patch. Therefore, spatial distribution of bird community during non-breeding season is largely resource driven. In this study also, I did not find any model that could explain variation in bird density during non-breeding season for hill and moist forest. Moreover birds were uniformly distributed across the disturbance gradient and had higher within plot variation for these two forest types (Figure D.1).

4.4.4. Response of bird community composition to habitat variables

Distribution and abundance of bird species is shown to be influenced by configuration (physiognomy) and composition (floristics) of the vegetation in their habitat (Rotenberry, 1985; Bersier & Meyer, 1994; Lee & Rotenberry, 2005; Jayapal et al., 2009) as well as by social cues (Mönkkönen et al., 1999; Fletcher et al., 2005).

Vegetation structure acts as a proxy for age, predation pressure (Whittingham & Evans, 2004), disturbance, and abundance of food resources. On the other hand, vegetation composition indicates the diversity of food resources, foraging and nesting niches. The relative influence of these two components varies as a function of the spatial scale over which bird–habitat relationships are examined. Rotenberry (1985) observed that physiognomy is crucial at larger scale and floristics at local level in distribution of birds. In this study, I did not find any strong association of bird composition with either overall vegetation structure or composition. Small-scale extractive disturbances also led to increased similarity in bird composition among sampling plots. For instance, grazing in hill forest and firewood collection in dry and moist forest resulted in increased similarity among sampling plots. All these disturbances adversely affected the specialist species (e.g., ground dwelling, trunk-bark feeders) and attract generalist species.

L.camara density, a vegetation structural attribute, was significantly associated with bird composition in dry forest. *L.camara* was major disturbance-induced change in understory of drier forest of the study area. It significantly influenced both bird community richness and abundance across seasons in all forest types. Therefore, a significant association of *L.camara* with bird community composition was expected. Aravind et al. (2010) also found a significant increase in the evenness of bird species with increasing *L. camara* density. This homogenity was attributed to increase in abundance of some generalist birds across disturbance levels. Therefore, an apparent increase in bird species richness and density should not be considered as a positive influence of *L. camara* on bird community as it is leading to biotic homogenization which has been shown as one of the major outcomes of invasion in several other taxa (Rooney et al., 2004; Holway & Suarez, 2006; Hejda et al., 2009).

CHAPTER 5

Response of avian foraging guilds to small-scale extractive disturbances

5.1. Introduction

It is often impossible to investigate the response of each and every species to modification of their resources. Therefore, researchers usually group species into guilds for easier understanding of ecological patterns. Species within a guild may or may not belong to a taxonomic group but compete for similar resources i.e., food, nesting etc (Root, 1967; Simberloff & Dayan, 1991). When using guilds for management purposes, biologists assume that species in a guild respond similarly to environmental change (Verner, 1984), a fact which may be of use in managing and monitoring forest ecosystem.

Response of bird species to habitat modification have been investigated by grouping them according to their food requirements (Thiollay, 1992; Sigel et al., 2006), foraging strata (Sekercioglu, 2002; Raman & Sukumar, 2002) and on the basis of ecological niche breadth (Julliard et al., 2004; Devictor et al., 2008). Diet, an important ecological trait, in particular, has been used more regularly in studies examining the response of species to habitat alterations (Lim & Sodhi, 2004; Sigel et al., 2006; Gray et al., 2007). Birds with largely insectivorous diet have been found to be extremely sensitive to habitat disturbance and exhibited considerable decline in various forest types (Canaday, 1996; Sekercioglu, 2002; Sigel et al., 2006). Habitat disturbance in forested area often results in colonization of an area by ruderals or grass species which provide food resources for grain/seed eating birds. Therefore, granivorous and omnivorous birds, on the contrary, are positively influenced by habitat disturbance (Barlow et al., 2002; Gray et al., 2007; Raman & Sukumar, 2002).

Studies have been conducted to assess the sensitivity of birds threatened by loss or degradation in their micro-habitat niche. Birds specialized in feeding on trunk-bark found to be sensitive to management practices leading to altered structure of forest patch. Understory insectivore is another highly sensitive guild that declines significantly due to disturbance-mediated changes in vegetation structure and fragmentation (Sekercioglu, 2002; Barlow et al., 2006)

chapter 3 of this thesis presents the significant changes brought about by extractive disturbances in vegetation structure and shrub composition in the study area. I expect that such changes in the vegetation and habitat properties, would modify the abundance and composition of food resources of the birds. Eggleton et al. (1996) examined the termite abundance, biomass and species richness in five disturbance levels (primary forest, old secondary forest, young plantation, weeded *Chromolaena* fallow, and completely cleared forest) in a forest reserve of southern Cameroon. Both primary and old secondary forest had the highest value for all three parameters whereas highly disturbed and cleared forest had the lowest. Turner & Foster (2009) studied the effect of oil palm plantations on arthropod abundance and biomass in evergreen dipterocarp forest of Malaysia. He reported significantly low abundance and biomass of arthropod in oil palm plantation in all micro-habitats (canopy, leaf litter and epiphytes) compared to primary forest. Interestingly, the effects of disturbance were not similar for all the insect species, leading to severe decline in abundance of few whereas density enhancement in others (Eggleton et al., 1996; Fermon et al., 2000; Uehara-Prado et al., 2007).

Fodder collection or lopping of fruiting trees (*Ficus sp.*, *Bridelia retusa Terminalia sp.Embelica officinalis* and *Ziziphus sp.*), is also expected to reduce the overall abundance fruits and flowers. These changes could lead to changes in abundance and composition of food resources for frugivorous and nectarivorous birds. Another widespread effect of small-extractive disturbances in this landscape is the invasion of exotic shrub *L.camara* that produces flowers and fruits almost year round (*Pers.Obs*). Considering potential changes in the food resources composition and abundance, it is essential to investigate the effect of disturbance on the foraging guilds. Such inquiry has immense relevance for the park managers to regulate the harvesting of critical resources during particular season for birds.

In this chapter, I address the following research questions:

1. Whether and how bird foraging guilds vary across season within a particular forest type.

2. How do different foraging guild vary across a disturbance gradient within each forest type?
3. Which habitat variables out of vegetation structure and its composition and small-extractive disturbances explain the variation in bird guild density during breeding and non-breeding seasons?

This study was carried out in a contiguous stretch of Shiwalik landscape Three dominant forest types namely dry plain Sal forest (hereafter 'dry forest') in south of the Shiwalik ridge, moist Shiwalik Sal forest (hereafter 'moist forest') in the north–facing slope of Shiwalik ridge and dry Shiwalik Sal forest in the hilly tracts (hereafter 'hill forest') of the ridge (Champion & Seth, 1968) were for the study (Figure 2.1).

A total of 30 sampling grids of 1 km ^{2} were selected across the landscape. Each grid had nine sampling point and at each point, nested circular plots were established for enumerating vegetation characteristics, anthropogenic disturbances and bird community (Figure 2.6). Variable–radius point transect method (Bibby et al., 1992) was used to collect data on bird communities (See chapter 2 for details).

5.2. Data Analysis

5.2.1. Categorization of birds into foraging guilds

To investigate the effect of habitat modification and potential modification in food resources birds were categorized into different feeding guilds. This was done at coarse and fine level. At the coarser level, birds were divided into five major foraging guilds: insectivores, frugivores, nectarivores, granivores and omnivores. At finer levels, birds were categorized into nine foraging guilds Table 5.1. In the present study, the birds were kept in particular category of feeding guild based on their food habits provided in literature (Ali & Ripley, 1968; Grimmett et al., 1999; Mohan, 2007) coupled with personal observations during the fieldwork.

Table 5.1.: Classification of birds into major and fine foraging guilds on the basis of their diet.

Major guild	**Fine foraging guild**	**Food material**	**Example**
Insectivore	Canopy–insectivore	Feeds on insects avialable in tree canopies	Cuckoo shrikes,minivets, leaf warblers
	Sallying insectivores	Included birds sallys at various height to catch insects	Flycatchers, drongos, Bee-eaters
	Understory insectivores	Feed on insects available in shrubs and leaf litter	Babblers, thrushes, warblers
	Trunk-bark feeders	Specialize in feeding on insects present in the tree bark and branches	Woodpeckers, nuthatches and tit
Frugivouors	Frugivorous	Included birds feeding on fruits and ocassionally insects	Green pigeon, barbets and hornbills
	Fruit-seed-nectar-insectivores	A very generalist bird guild with variety of food items	Starlings, bulbuls and Parakeets
Necatarivorous	Nectar-insectivore	Primarily feed on nectar & pollen and ocassionally include insects and fruits in their diet	Flowerpeckers, sunbirds
Granivorous	Granivorous	Included birds adapted to feed on grains, seeds and ocassionally on insects	Finches, pipits and doves
Omnivorous	Omnivorous	Birds feeding on almost all types of plant materials, insects and carrion as well	Crows, Treepies, Magpies

5.2.2. Guild density estimation

Since abundance/density estimated from raw counts may be highly biased due to differential detectability of species, it is advisable to correct for this detection bias in density calculations. Program DISTANCE corrects for bias in detection probabilities by fitting a detection function (Thomas et al., 2010). Species specific densities were calculated by pooling species with similar detections distances together (Alldredge et al., 2007; Mohan, 2007). Birds were categorized in the three groups based on their detection behavior. Species detected (i) closer to the observer (within 30 m distances), (ii) at medium distances (from 30 to 50 m distances) and (iii) and the ones detected far away (beyond 50 m). Later each species was assigned into a major & a fine foraging guild and densities were summed for all the species for a particular guild. I used one way ANOVA followed by post hoc Tukey's HSD test for examine differences in guild density across forest within a given season.

5.2.3. Modelling fine foraging bird guilds as a function of disturbance and vegetation

Response of fine bird guilds to habitat modification to disturbance was analyzed by modelling their densities in mixed effects modelling framework to account for the nested sampling design (Bolker et al., 2009; Zuur et al., 2009a). Modelling was done only on the fine foraging guilds. I selected vegetation and disturbance variables expected to have an influence on the fine foraging guild based on literature survey (Table 5.1). Correlation between explanatory variables was checked before including them in the model and only non-correlated variables were used in the model building. Due to the change in the bird species composition between season and habitat, separate models were built for each forest type for summer (breeding) and winter season (non-breeding).

Linear and Poisson mixed effect models (Zuur et al., 2009b; Crawley, 2012) with logical alternate combinations of disturbance indicators as fixed effects and random effects of plots were built and compared by Information theoretic approach. Akaike information criterion for small sample sizes (AICc) was opted for model selection ((Burnham & Anderson, 2002)). All explanatory variables were z-standardized (with zero mean and unit standard deviation) to make the variables mutually comparable. Analyses were carried out in the statistical software R version 2.14.0 (R Development Core Team, 2011) with the aid of "lme4" package (Bates et al., 2014).

Table 5.2.: Description of habitat variable considered a priori to potentially influence avian guild attributes, and the rationale for their inclusion in candidate models. Up (↑) and down arrows (↓) indicate increases and decrease in species number and density respectively.

Predictor	**Rationale**	**Sensitive guild**	**Reference**
Lopping	*Direct*: Recent lopping removes fodder from the trees and decrease food abundance (Fruit and insect) in the canopy *Indirect*: Increased sunlight reaching to ground after lopping might enhance the understory growth, invasion of exotic & weedy shrubs and enhanced food resources in shrub layer	↓CI,↓FSNI,↑O,↓NI,↓UI	(Chettri et al., 2001)
Timber extraction	*Direct*: Less food resources due to removal of entire tree and large canopy openings.	↓CI,↓F,↑O,↑G,↓TBF, ↓UI	(Sekercioglu, 2002)
Firewood collection	*Direct*: Removal of secondary and tertiary branches will reduce the food resources (insects) and perch sites. *Indirect*: Increased sunlight reaching to ground after firewood collection will enhance the understory growth, invasion of exotic & weedy shrubs and enhanced food resources.	↑O, ↓TBF, ↓SI	(Chettri et al., 2005)
Grazing	*Direct*: Reduction in food resources especially ground dwelling insects. *Indirect*: Inhibit sapling establishment, lead to establishment of weedy species.	↓UI, ↓G	(Martin & Possingham, 2005)
Fire	*Direct*: Fire would directly reduce the food resources for birds (insects, seeds etc.). *Indirect*: Promotes growth of grasses and thereby increase grain/seed abundance.	↓UI,↓SI,↑G	(Barlow et al., 2002)
Tree basal area	*Direct*: Indicate old aged forest and provide food resources.	↑TBF, ↑IU	
%canopy cover	*Direct*: Decreased visibility and canopy closeness. *Indirect*: Increase in moist conditions, increased insect abundance.	↑CI,↑UI, ↓FSNI,↓NI	(Chettri et al., 2001)
Shrub volume	*Direct*: Increased food and nesting resources.	↑ UI	
Lantana cover	*Direct*: Year round availability of food and cover.	↑UI,↑FSN,↑NI	(Aravind et al., 2010)

5.3. Results

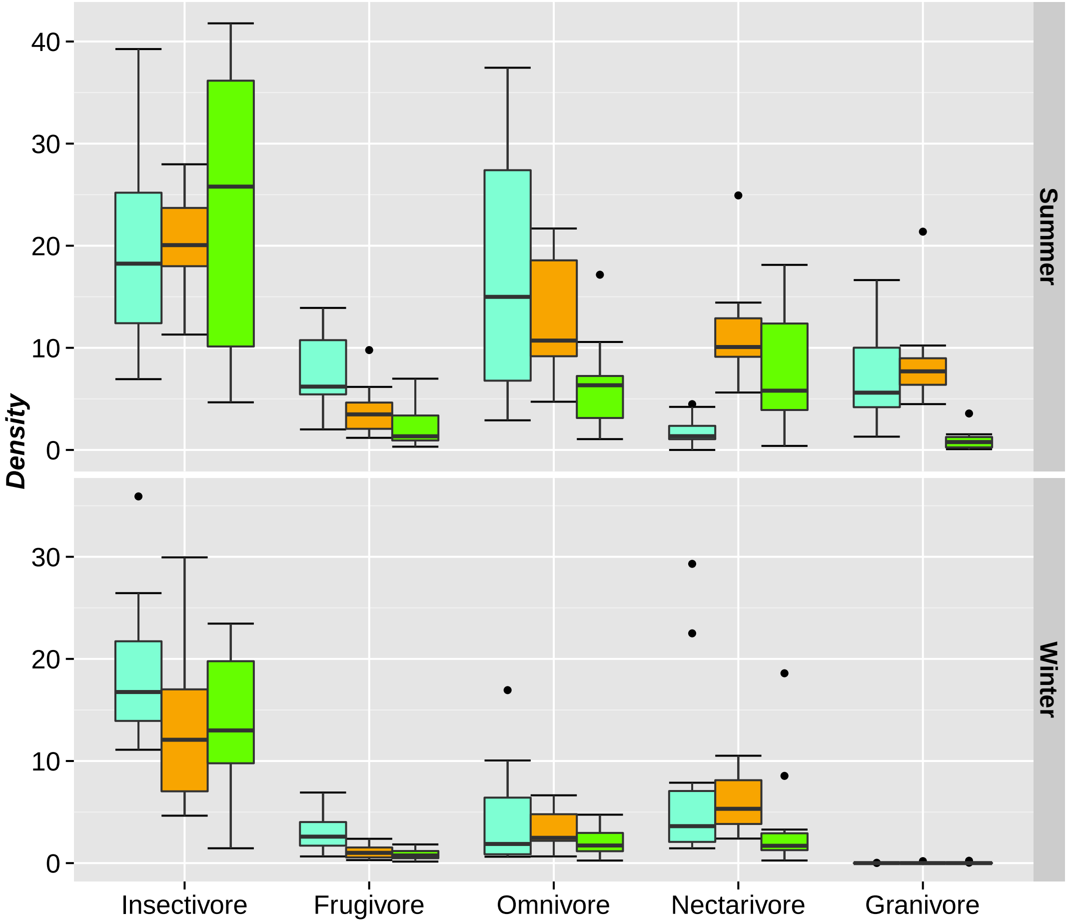
5.3.1. General patterns in major foraging guild densities across and within forest types

Out of all the foraging guilds, insectvores had the highest densities in all forest types across seasons. There was no difference in the density of insectivore guild across forest types between breeding and non-breeding season [*Breeding*: F(2,27) = 0.39, p=0.18; *Non-breeding*: F(2,27)=1.77, p<0.001] (Figure 5.1). Frugivore guild had highest densities in dry forest compared to other forests [*Breeding*: F(2,27)=725, p <0.001; *Non-Breeding*: F(2,27)=9.77, p <0.001]. Omnivore guild had lowest density in moist forest during breeding season and there was no difference during the non-breeding season [*Breeding*: F(2,27)=3.38, p=0.03; *Non-breeding*: F(2,27)=1.16, p = 0.32] (Figure 5.2). Nectarivores had the lowest density in the dry forest during the breeding season but there was no difference in the density across hill and moist forest. Also, there was no difference in the density of the guild during non-breeding season [Breeding: F(2,27)=11.25, p <0.001]. Granivores was observed during summer season only (Figure 5.1). Dry and hill forest had similar densities of granivore guild [*Breeding*: F(2,27)=9.81, p <0.001] during breeding season. There was no difference in the density of granivorous guild across forest types during non-breeding season [*Non-breeding*: F(2,27)=0.48, p=<0.62]

5.3.2. General patterns of major foraging bird guild along disturbance gradient

Densities of insectivorous and nectarivorous guild did not vary significantly across season in dry and moist forest but in hill forest densities of both the guilds (insectivore: t=2.89, p=0.05; nectarivore: t=2.48, p=0.04) were significantly higher during the breeding season. Both frugivorous and omnivorous guilds exhibited higher densities during breeding season across forest types. Granivorous guild was represented only during the breeding season in all forest types. At plot level, I did not find any pattern in density of the foraging guild across a disturbance gradient during both seasons (Figure 5.2).

Figure 5.1.: Major guild densities (mean ± SE per hectare) across forest types for two seasons. Cyan=dry forest, orange=hill forest and green=moist forest.



5.3.3. Response of fine foraging bird guilds to vegetation and disturbance variables

Breeding Season

Opening of canopy and increasing tree diversity led to decrease in canopy- insectivores in dry forest (Table 5.3). However in hill forest, increasing tree diversity elevated the density of the canopy-insectivore guild (Table 5.4). In the moist forest, firewood collection and fire had a negative influence of canopy insectivores (Table 5.5)

Understory-insectivore guild decreased with increase in overall canopy closure and timber extraction in dry forest (Table 5.3). In hill forest, understory-insectivore guild decreased with fire but increased with *L.camara* cover. In moist forest, lopping resulted in the decline of understory-insectivore guild whereas increasing *L.camara* cover benefited it (Table 5.4).

Densities of sallying insectivore guild increased with increasing *L.camara* density and shrub diversity in dry forest (Table 5.3). In hill forest, the best model explaining the variation in sallying insectivore included canopy cover but its effect size was not significant. In moist forest, canopy opening and fire negatively influenced this guild (Table 5.5).

None of the vegetation and disturbance variables could explain the variation in trunk-bark feeder guild across forest types (Tables 5.3, 5.4, 5.5).

In both dry and hill forest, frugivorous guild did not show any strong relationship with vegetation and disturbance variables. Interestingly, in moist forest *L.camara* increased the density of this guild whereas timber extraction caused its decline (Tables 5.3, 5.4, 5.5).

Non-breeding Season

Canopy-insectivore guild density decreased with increasing tree diversity but increased with increasing tree density in dry forest.In hill forest, lopping and presence of fire caused decrease in density of canopy insectivores. In moist forest, fire reduced density of this guild.

Understory-insectivorous guild, in dry and hill forest was related to lopping pressure. Density of this guild increased with increasing lopping in dry forest whereas it declined with lopping in hill forest (Table 5.3) and (Table 5.4). In moist forest, it was positively associated with the tree basal area (Table 5.5).

Sallying-insectivore guild in dry and hill forest was associated with tree diversity but the relationship was negative in dry forest and positive in hill forest (Table 5.3) and (Table 5.4).In moist forest, it decreased with fire and grazing and increased with increasing shrub volume.

Trunk-bark feeder guild increased in density with increasing tree density and tree basal area in dry forest (Table 5.3). In hill forest, it decreased with increasing tree density and lopping pressure (Table 5.4). In moist forest, increase in canopy cover positively influenced the density of this guild whereas increased tree density had an opposite effect (Table 5.5).

Vegetation and disturbance variables did not explain much about the variation in density of frugivorous guild in dry and hill forest as the best model had very low value of correlation coefficient. In moist forest, frugivorous guild increase in density with timber extraction but decrease with increasing tree density (Table 5.5).

Fruit-seed-nectar-insectivore guild was related to vegetation diversity in both dry and hill forest but none of the variable was statistically significant (Table 5.3) and (Table 5.4). In moist forest, increase in *L. camara* cover resulted in increased density for this guild (Table 5.5).

Omnivore guild increased with increasing tree diversity in dry forest (Table 5.3). In hill and moist forest, fire caused an increase in the density of this guild (Table 5.4 and Table 5.5). It was also found to be positively influenced by increasing *L.camara* density in hill forest (Table 5.4).

Density of nectar-insectivorous guild, increased with vegetation diversity in dry forest (Table 5.3). *L.camara* density emerged as an important predictor for this guild and positively influenced the density of this guild in both hill and moist forest. In hill forest, density of this guild declined with fire (Table 5.4) and (Table 5.5).

Figure 5.2.: Foraging guild densities (no. of individual ± SE (km^{-2})) for breeding and non-breeding season across disturbance gradient (plots are arranged in increasing order of disturbance) in all forest types.

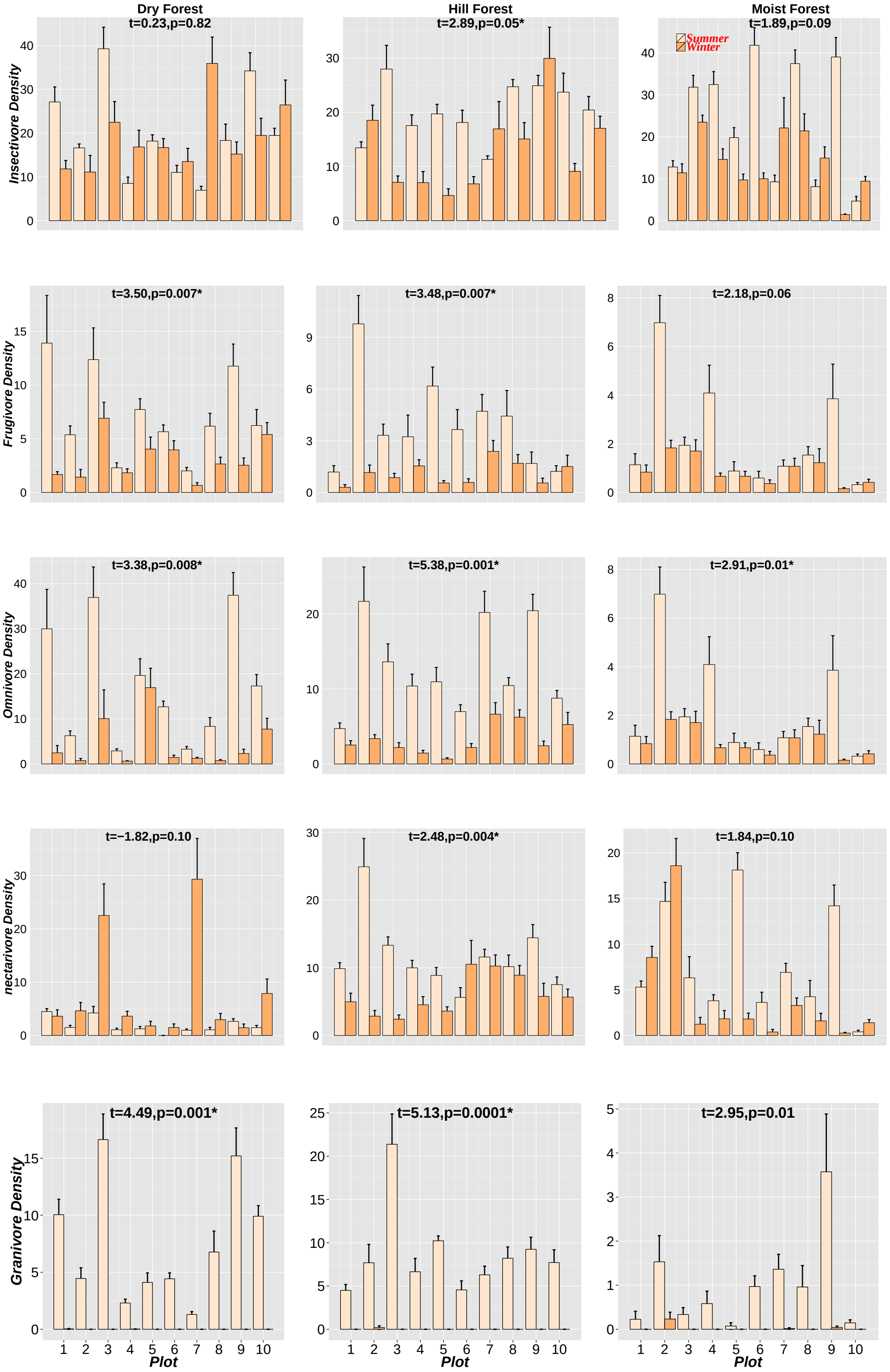


Table 5.3.: Summary of generalized linear mixed-effects model analysis showing coefficient estimates for fine guild densities in **Dry forest** during breeding and non-breeding season. Since variables had been scaled and centred, predictors are expressed in unit standard deviations. Estimates with absolute values greater than two standard errors indicated in bold. Coefficient of correlation r is the result of correlation between model-predicted and observed values. Correlations significant at P = 0.01 indicated in bold.

Fine foraging guild	**Breeding**			**Non-breeding**		
	Predictors	$\beta \pm (SE)$	Correlation coefficient	Predictors	$\beta \pm (SE)$	Correlation coefficient
Canopy-insectivore	Tree diversity	-0.38 (0.21)	0.73	Tree diversity	-0.35 (0.21)	0.37
	% canopy cover	-0.15 (0.10)		Tree density	0.15 (0.09)	
Understory-insectivore	Timber extraction	**-0.27 (0.11)**	0.62	Shrub diversity	1.15 (0.63)	0.42
	Lopping	0.24 (0.13)		Lopping	**0.40 (0.17)**	
	% canopy cover	**-0.30 (0.12)**		% canopy cover	-0.33 (0.19)	
Sallying-insectivore	Lantana density	**0.18 (0.09)**	0.69	Tree density	0.11(0.06)	0.23
	Shrub diversity	**0.74 (0.29)**		Tree diversity	-0.19 (0.14)	
	% canopy cover	-0.16 (0.09)				
Trunk-bark feeder	Fire	-0.30 (0.17)	0.48	Tree density	**0.25 (0.09)**	0.61
	Tree diversity	0.25 (0.18)		Tree basal area	**0.29 (0.09)**	
Frugivore	Shrub diversity	0.02 (0.17)	0.18	% canopy cover	0.07 (0.05)	0.72
	Lopping	0.08 (0.05)		Tree diversity	0.11(0.10)	
Fruit-seed-netar-insectivore	Firewood collection	-0.22 (0.12)	0.88	Tree diversity	-0.13 (0.24)	0.74
	% canopy cover	**-0.32 (0.14)**		Shrub diversity	0.49 (0.35)	
Omnivore	% canopy cover	-0.11 (0.08)	0.64	Tree diversity	**0.27 (0.09)**	0.59
	Shrub diversity	0.39 (0.23)				
Granivore	% canopy cover	**-0.25 (0.09)**	0.80			
Nectar-insectivore	Grazing	**-0.25 (0.12)**	0.74	Shrub diversity	0.16 (0.54)	0.60
	Tree diversity	0.39 (0.23)		Tree diversity	0.21 (0.34)	

Table 5.4.: Summary of generalized linear mixed-effects model analysis showing coefficient estimates for fine guild densities in **Hill forest** during breeding and non-breeding season. Since variables had been scaled and centred, predictors are expressed in unit standard deviations. Estimates with absolute values greater than two standard errors indicated in bold. Coefficient of correlation r is the result of correlation between model-predicted and observed values. Correlations significant at P = 0.01 indicated in bold.

Fine foraging guild	**Breeding**			**Non-breeding**		
	Predictors	$\beta \pm (SE)$	Correlation coefficient	Predictors	$\beta \pm (SE)$	Correlation coefficient
Canopy-insectivore	Fire	-0.30 (0.23)	0.52	Lopping	**-0.31 (0.12)**	0.37
	Firewood collection	**-0.19 (0.09)**		Fire	**-0.33 (0.25)**	
Understory-insectivore	Fire	-0.31 (0.19)	0.59	Shrub diversity	**-0.48 (0.24)**	0.45
	Lantana density	0.15 (0.09)		Grazing	0.25 (0.15)	
				Lopping	-0.14(0.13)	
Sallying-insectivore	% canopy cover	0.25 (0.09)	0.63	Tree diversity	0.15(0.20)	0.55
Trunk-bark feeder	Tree density	-0.31 (0.21)	0.22	Tree density	-0.11 (0.07)	0.75
	Loping	-0.14 (0.20)		Lopping	-0.10 (0.08)	
Frugivore	% canopy cover	-0.12 (0.08)	0.41	Tree diversity	-0.09 (0.08)	0.41
	Shrub diversity	0.35 (0.16)		Tree crown cover	0.07(0.04)	
Fruit-seed-netar-insectivore	Shrub diversity	**0.61 (0.24)**	0.78	Tree diversity	0.29 (0.19)	0.66
	Lantana density	-0.07 (0.11)		Shrub diversity	0.01(0.02)	
Omnivore	Grazing	0.13 (0.07)	0.30	Fire	**0.24 (0.10)**	0.62
	Lantana cover	0.13 (0.06)		Lantana density	**0.10 (0.04)**	
Granivore	Grazing	0.16 (0.13)	0.53			
	Firewood collection	0.14 (0.09)				
Nectar-insectivore	Firewood collection	**-0.18 (0.07)**	0.76	Fire	**-0.65 (0.27)**	0.59
	Lantana density	**0.34(0.08)**		Lantana density	**0.25 (0.12)**	

Table 5.5.: Summary of generalized linear mixed-effects model analysis showing coefficient estimates for fine guild densities in **Moist forest** during breeding and non-breeding season. Since variables had been scaled and centred, predictors are expressed in unit standard deviations. Estimates with absolute values greater than two standard errors indicated in bold.

Fine foraging guild	**Breeding**			**Non-breeding**		
	Predictors	$\beta \pm (SE)$	Correlation coefficient	Predictors	$\beta \pm (SE)$	Correlation coefficient
Canopy-insectivore	Tree diversity	**2.08 (0.39)**	0.75	Fire	0.19 (0.09)	0.56
Understory-insectivore	Lopping	**2.86 (0.92)**	0.77	Tree basal area	0.33 (0.16)	0.79
	Lantana density	**1.54 (0.69)**		Grazing	0.25 (0.15)	
	Grazing	-1.75(1.29)				
Sallying-insectivore	Fire	**-0.85 (0.34)**	0.63	Shrub volume	**0.21(0.07)**	0.67
	% canopy cover	**-1.21 (0.32)**		Grazing	-0.14 (0.10)	
	Tree diversity	1.37 (0.84)	0.75	Fire	-0.08 (0.06)	
Trunk-bark feeder	Tree diversity	-0.34 (0.18)	0.86	Tree density	-0.19 (0.08)	0.75
	Tree basal area	-0.17 (0.09)		Lopping	-0.13 (0.06)	
Frugivore	Lantana density	0.09 (0.03)	0.40	Timber extraction	0.11 (0.04)	0.77
	Shrub diversity	0.35 (0.16)		Tree crown cover	-0.12 (0.04)	
Fruit-seed-netar-insectivore	Lantana cover	0.25 (0.08)	0.88	Lantana cover	0.28 (0.09)	0.67
	% canopy cover	-0.15 (0.08)		Shrub diversity	0.01(0.02)	
Omnivore	Grazing	-0.34 (0.09)	0.88	Fire	0.11 (0.06)	0.62
	Lantana cover	0.21 (0.09)				
	Lopping	0.23 (0.11)				
Granivore	% canopy cover	-0.25 (0.08)	0.58			
	Firewood collection	0.14 (0.09)				
Nectar-insectivore	Tree diversity	0.05 (0.3)	0.80	Lantana cover	0.39 (0.12)	0.83
	Shrub diversity	0.16(0.28)				

5.4. Discussion

Small-scale extractive disturbances are gradually depleting the micro-habitat niches and associated food resources of the specialized guilds. For example, lopping and firewood collection led to decline of canopy insectivore guild and nectar-insectivore guilds in the naturally open and heavily lopped hill forest. Out of the disturbance variables, lopping and fire affected a majority of guilds. Timber extraction, firewood collection and grazing too influenced guild density but effect of these disturbances were restricted to particular season and forest types. For example, fire had led to decrease in the density of sallying insectivore guild in the moist forest but neither fire nor other disturbance variables influenced this guild in other forest types. Moreover, for most guilds the effects of disturbance can be translated via vegetation modification rather direct effect of disturbance. Among all the vegetation variables selected for modelling the guild density, canopy cover and *Lantana camara* density in particular emerged as important determinants for a large number of guilds. Another interesting result was the absence of any apparent pattern in densities of any guild at the plot level (1 km^2). The reason for this in the study area is the high heterogeneity in the disturbance levels among the intensive sampling points within a plot.

5.4.1. Seasonal changes in bird guilds

Tropical forests do not vary drastically in their weather conditions across year in contrast to temperate forests. However, seasonal changes in avifauna to altering rainfall and precipitation are very well documented for these forests (Miller, 1963; Leck, 1972; Karr, 1976b). Year round availability of foliage ensure insect availability for insectivorous guild of tropical forests (Karr, 1976b). Conforming with the previous studies (Mohan, 2007), density of insectivorous and nectarivorous guild did not vary seasonally within the dry and moist forest of the study area. Frugivorous and omnivorous guilds exhibited considerable enhancement in density from winter to summer across forest types. Cueto & Lopez de Casenave (2000) in coastal woodland of Argentina also found a similar pattern of minimal changes in the abundance of insectivorous guild across seasons but significant changes in frugivore-insectivore guild. Moreover, densities for almost all guild were higher during the breeding than non-breeding season which is in consensus with studies in tropical forest (Karr, 1976b; Mohan, 2007).

5.4.2. Response of different fine foraging guilds to disturbances

Insectivores

Insectivorous birds play an important role in controlling population of invertebrates and consequently herbivory in forests (Van Bael et al., 2003b), plantations (Kellermann et al., 2008; Mooney et al., 2010) as well as in agroforests (Bael et al., 2008).In Europe the forest department manages the herbivory damage on the economically important tree species by augmenting the density of insectivorous birds through placing nest boxes in forests (Takekawa et al., 1982). Simultaneously, this guild is highly sensitive to habitat loss (Lim & Sodhi, 2004), fragmentation and (Sekercioglu, 2002), habitat degradation (Gray et al., 2007). Insectivorous birds show close association with the structural complexity of vegetation and therefore its loss due to small–scale extractive disturbances and associated increase in sunlight in the study area might be the strongest reason for their negative relationship with disturbance variables. Pearson explained that increased direct sunlight could influence the search patterns of insectivore birds leading to their decline in disturbed areas (Pearson, 1977).

Canopy insectivores includes birds feeding largely on insects in the tree canopies. This guild showed high sensitivity to lopping and firewood collection in hill forest. These disturbances reduce the amount of food resources in the foliage and thereby could reduce the density of canopy insectivore guild during breeding and non-breeding seasons. Fjeldså (1999) in humid forest of Tanzania-Malawi Mountains found serious decline in canopy insectivores owing to disturbance. In both hill and moist forests, fire also emerged as an important variable negatively associated with guild. Consequences of recent fires act similarly to other disturbances as it also leads to reduction in resource availability. In Amazonia, Barlow et al. (2002) found that insectivorous guild was negatively affected by the fire and were less abundant in burnt areas.

Understory-insectivores found to be particularly sensitive to habitat disturbance (Sekercioglu, 2002; Stratford & Robinson, 2005; Powell et al., 2015). However, most of our knowledge about the possible reasons for their increased sensitivity comes from fragmentation studies in temperate forest. In the study area, the only large-scale disturbance is the past timber extraction in dry and moist forests which resulted in decline of this guild. Similarly, livestock grazing in moist forests negatively influenced this guild possibly by removing shrub layer. Increased xeric conditions after disturbance often lead to decrease in leaf litter and soil dwelling invertebrates due to desiccation (Eggleton et al., 1996). Moreover, there could an indirect influence of such large-scale disturbance on this guild in terms of loss of nest sites, increased competition by sympatric generalist species (Ford et al., 2001) and increased predation in highly disturbed areas. Interestingly, increasing lopping disturbance had a positive influence on this guild especially in moderate to dense canopy of dry and moist forest. Lopping and other small-scale disturbance lead to increased sunlight reaching to the ground and consequently increased shrub growth possibly increasing the overall food or nesting resources for this guild.

Sallying-insectivore have been shown to tolerate and get benefited by low level of disturbance. For example Johns Johns (1991) while investigating the effect of selective logging on Brazilian Amazonia found that this guild was benefited by the increased insect abundance in forest clearing/ edges (Johns, 1991). However, sallying insectivores could not tolerate high level of disturbance due to logging and fire (Thiollay, 1992; Barlow et al., 2002; Arcilla et al., 2015). Conforming with other studies, slight opening of canopy in otherwise closed intact dry and moist sal forests led to increase in the density of this guild but on the contrary it increased in density with increasing canopy cover in fairly exposed hill forest. Also, fire during the breeding season, possibly depleting foraging substrates for this guild led to decline in their density. Increase in understory cover due to *L.camara* invasion enhanced density of this guild in dry forest during breeding season.

Trunk-bark feeder guild seems to be less affected by small-scale changes in the micro-climatic conditions of their habitat (Johns, 1991), yet, large scale disturbance such as logging and management practices have been shown to be detrimental for this particular guild (Drever et al., 2008). In this study, trunk bark feeder guild did not show sensitivity to small-scale disturbances rather associated with increasing basal area of trees and canopy closeness in Sal forest, indicating forest maturity and low level of disturbances in the tree layer. This finding is interestingly similar to the observations of Johns (1991) in Brazilian Amazonia where this guild was minimally effected by the changes in forest structure due to selective logging. According to Johns (1991), this could be attributed to the presence of main trunk as foraging substrates and also use of more than once foraging tactic (probing on bark, foliage gleaning and occasional flycatching).

Frugivores and Fruit-seed Nectar Insectivores

Frugivorous birds due to their mutualistic interactions with fruiting trees provide an important service of dispersing the seeds away from parent plant. More than 90% of tropical trees have evolved to produce large, lipid-rich fruits adapted for animal dispersal (Howe, 1984), the decline of avian frugivores may have serious consequences for forest regeneration. Several examples exist (Brash, 1987; Cordeiro & Howe, 2001, 2003) of tropical fruiting trees that either failed to become re-established after harvest or became less numerous in fragments where the frugivorous bird responsible for the dispersal of their seeds has declined or disappeared.

However, effects of disturbances on frugivorous and fruit dependent guilds vary considerably (Thiollay, 1992; Gray et al., 2007). Johns (1991) found an increase in abundance of fruit eating macaw in logged areas. Whereas in a meta-analysis done using 57 studies investigating effect of moderate disturbances on avian guilds, Gray et al. (2007) observed minimal decline in frugivore abundance following disturbance. Disturbance activities often results in increased flower and fruit abundance and associated increase in frugivores (Moegenburg & Levey, 2002). As stated earlier, canopy opening due to disturbances has results in invasion of weedy species, *L. camara*. It spreads due to small-scale extractive disturbances. *L. camara* provides a constant supply of fruits for small and medium sized birds year round. Even large canopy frugivores such as hornbills and barbets have been observed to feed on *L. camara* fruits occasionally (*Pers.Obs.*). Frugivorous and fruit–seed–nectar insectivorous guild of moist forest were significantly enhanced by *L. camara* density during breeding season. Moist forest is largely Sal dominated with very few fruiting trees and therefore increased fruit availability due to *L. camara* resulted in increase in density of this guild. Disturbances in this study did not change the vegetation composition significantly (see chapter 3 result). Tree and shrub diversity was found to be influencing this guild rather than disturbances. Ever fluctuating resource availability in tropical forest has made these guilds successful in exploiting the disturbed areas as well (Johns, 1991).

Omnivores

This guild included birds largely from corvid family that feed on a variety of food resource and exploit various foraging habitats thus are one of the most generalist guilds. In this study, I found an increase in abundance of this guild with increasing small-scale extractive (lopping and grazing) disturbance, canopy opening as well as with fire. Studies across different taxa are also show similar results where generalist species were less negatively affected by disturbance or rather favoured by unstable environments (Devictor et al., 2008).

Granivores

In a recent meta-analysis of moderate disturbance (e.g., selective logging) studies in tropical forest by Gray et al. (2007), this guild consistently increased in abundance across all biographical regions of the world.In Singapore, Lim & Sodhi (2004) also observed significant increase in abundance of granivorous birds with increasing public housing. Grass species often colonize the area after a disturbance event especially after fire (Barlow et al., 2002). In this landscape as well, I found that increase in small-scale extractive disturbances and canopy opening had a positive influence on this guild especially in moist forest that is otherwise closed and supports no or minimum grass cover. This increase in abundance is attributed largely to the influx of doves.

Nectar-insectivores

Nectar-insectivore guild known as “genetic linkers” that help in maintaining the genetic diversity by exchanging genetic material between plants. This guild varies in its response to disturbances according to geographical regions. Gray et al. (2007) showed that studies from Asia has reported declines in the abundance of this group whereas no clear pattern was observed in studies pertaining to neotropics. In dry and hill forest, increasing disturbance due to grazing, firewood collection and fires led to decrease in the density of this guild. Whereas in moist forest none of the disturbance variables had any effect on this guild. *L. camara* cover on the other hand exhibited a positive influence on this guild in hill and moist forest. *L. camara* is known to produce large quantities of nectar which possibly had positive influence on this guild (Brown et al. 2002). However in a study from southern India, Aravind et al. (2010) did not find appreciable increase in this guild with increasing *L. camara* density.

5.4.3. Significance and limitations of guild approach

Analyzing response in terms of meaningful groups such as feeding guild receive appreciation for being cost effective and in identifying the broad patterns in species competing for similar resource. This approach also helps in understanding the underlying mechanism response of bird's to small-scale extractive disturbances. However, this approach suffers from some limitations.

The first concern regarding this approach is the possibility of bias if the species within a guild differ in their finer niche differentiation (Lim & Sodhi, 2004). For example, in the current study, trunk bark feeder guild was not influenced by disturbance as it is largely constituted by the woodpeckers. However, certain members of this guild such as nuthatches and tit are expected to decline in abundance with increasing firewood collection as they forage on the tertiary twigs rather the main trunk like woodpeckers (see chapter 6).

The second concern is the obscurement of patterns in less abundant species in case the guild has high numerical representation of a particular species. For example, I found the nectarivorous guild in the study area was benefited by *L.camara* cover in this study. This guild is represented by five species in the study area. However, 54% (1062 out of 1957) of the observations belonged to Oriental White-eye whereas the two flowerpeckers (Thick-billed Flowerpecker and Pale-billed Flowerpecker), that have never been observed to feed on *L.camara* nectar during the study period, contributed to only 9% (172 out of 1957) of the total observations.

Finally, species within a particular guild could vary in their other life history aspects. For example, fruit-seed-nectar guild, constituted by parakeets, barbets and bulbuls, was benefited by *L.camara* cover but the finer level analysis indicated that the few species, such as Rose-ringed parakeet and Common Myna had a significant negative correlation with *L. camara* cover particularly during the breeding season see chapter 6).

CHAPTER 6

Birds as indicators of small-scale extractive disturbance

6.1. Introduction

The global protected area network, now covering 14.6% of the earth's land surface (Butchart et al., 2015), conserves natural resources, ecological process and invaluable ecosystem services. However, long-term extraction of biomass at small-scale (e.g. firewood and fodder collection, livestock grazing etc.) by rural and forest dwelling people is emerging as one of the major reasons for their degradation. Such activities modify not only structure but also composition of the forest (Murali et al., 1996; Tilman & Lehman, 2001; Shahabuddin & Kumar, 2006). In order to control degradation and associated loss of biodiversity it becomes imperative for park managers to monitor changes in habitat due to these activities.

Landres et al. (1988) stated that direct monitoring of properties of interest should be carried out wherever possible. However, the task of monitoring a large wilderness area including hundreds or thousands of living species is impossible. Therefore, it is more practical and feasible to restrict monitoring observations to a few representative "indicator species" or key phenomena that reflect broader trends, and to measurements that give an indication of the general biological condition of the environment such as Ecological-Disturbance Indicator Species (EDIS) (MacKinnon et al., 1986; Simberloff, 1998; Caro, 2010). EDIS can be a species or a group of which serve as early warning system to an environmental change; they can also be used to find out the cause of an environmental problem (Caro, 2010).

Birds have been proved to be excellent EDIS owing to their strong association with habitat characteristics. Birds have been used as model taxa to observe habitat alteration (Canterbury et al., 2000; O'Connell et al., 2000; Jayapal et al., 2009), effects of management practices (Hansen et al., 1995; Sekercioglu, 2002; Drever et al., 2008), environmental contamination (Matz & Parsons, 2004; Papp et al., 2007) and small-scale extractive disturbances (Chettri et al., 2001; Shahabuddin & Kumar, 2006). Government agencies of various countries have been utilizing bird as indicators of biodiversity ((Beeton et al., 2006); `www.ebcc.info/pecbm`). Birds also have other advantages in monitoring projects. Several standardized census techniques are available, field identification is comparatively easy, and baseline ecological data are available for most species.

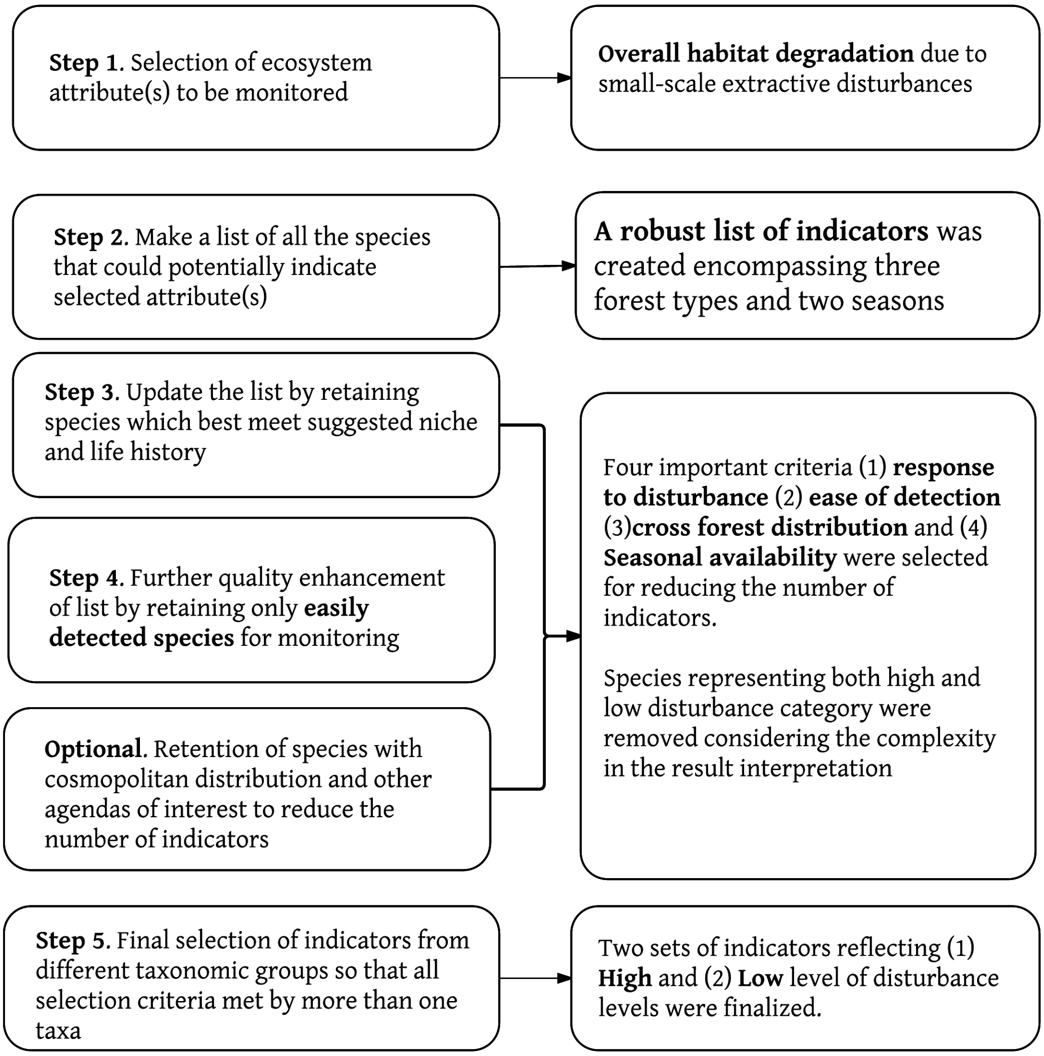
There have also been attempts to increase the robustness of the selected indicators. Multiple criteria have been suggested to be incorporated for the refinement of indicator list (Noss, 1990; Pearson & Cassola, 1992; Cairns Jr et al., 1993; Hilty & Merenlender, 2000). Among the various criteria suggested by researchers, high detection probability is the top criteria to the make monitoring process inexpensive and less time consuming (Noss, 1990). Additionally, a single indicator responding to a number of stressors will be helpful in simultaneous monitoring of various stresses which increase their utility and ensure their continuous use even if one of the stress elements disappears from the system (Gibbs et al., 1999; O'Connell et al., 2000).

Broad geographical distribution of an indicator is another important criteria that could help in monitoring multiple sites using single indicator (Noss, 1990; Pearson & Cassola, 1992). For monitoring the ecosystem health, species specialized in their habitat or food requirements could reflect the change faster than generalist species which could switch to other resources (Hilty & Merenlender, 2000; Carignan & Villard, 2002). Short generation time is another important criterion for selection of indicators which makes the changes visible sooner (Hilty & Merenlender, 2000). Similarly, resident species have more value as they can be used for year round monitoring but inclusion of migrants has also been suggested by researchers (Hilty & Merenlender, 2000; Gregory et al., 2005).

Despite being appealing to conservationists and park managers alike the idea of using a small set of indicators for monitoring has faced a lot of criticism as well. Noss insisted that no single indicator would be able to have all the desirable qualities and sometimes one attribute could be in conflict with other attributes (e.g, a specialist species generally have narrow distribution). The relationship between indicator and the stressor under investigation could vary across spatial scales (Banks-Leite et al., 2013). Therefore, indicators should be used while admitting and accounting their limitations (Simberloff, 1998).

In this chapter, following indicator selection and quality improvement framework by Hilty & Merenlender (2000), I identify bird species indicating different levels of disturbance as well as specific disturbances. Then using four selection criteria, I narrow down the indicators for future monitoring of small-scale extractive disturbances in the study area. Specifically, I addressed following research questions:

Figure 6.1.: Stepwise decision making framework for selection of indicator species adopted from Hilty & Merenlender (2000)



1. What are the bird species in the study area that indicate different levels of disturbance within a forest types, and are these indicators consistent in their response across forest types and seasons?
2. What is the relationship between selected indicator species with specific disturbances?

This study was carried out in a contiguous stretch of Shiwalik landscape Three dominant forest types namely dry plain Sal forest (hereafter 'dry forest') in south of the Shiwalik ridge, moist Shiwalik Sal forest (hereafter 'moist forest') in the north–facing slope of Shiwalik ridge and dry Shiwalik Sal forest in the hilly tracts (hereafter 'hill forest') of the ridge (Champion & Seth, 1968) were for the study (Figure 2.1).

A total of 30 sampling grids of 1 km ^{2} were selected across the landscape. Each grid had nine sampling point and at each point, nested circular plots were established for enumerating vegetation characteristics, anthropogenic disturbances and bird community (Figure 2.6). Variable–radius point transect method (Bibby et al., 1992) was used to collect data on bird communities (See chapter 2 for details).

6.2. Data Analysis

6.2.1. Estimation of densities for individual species

Since density estimated from raw counts may be highly biased due to differential detectability of species, it is advisable to correct for this detection bias in density calculations. Program DISTANCE corrects for bias in detection probabilities by fitting a detection function (Thomas et al., 2010). Species specific densities were calculated by pooling species with similar detections distances together (Alldredge et al., 2007; Mohan, 2007). Birds were categorized in the three groups based on their detection behavior. Species detected (i) closer to the observer (within 30 m distances), (ii) at medium distances (within 50 m distances) and (iii) and the ones detected far away (beyond 50 m). Species detected closer to the observer were generally small bodied birds such as Crimson sunbird, Black chinned babbler, warblers and nuthatches etc. which are often less skulking and are detected only after giving the aural cues.

Species detected at medium distances from the observer were parakeets, orioles, medium sized woodpeckers. Red jungle fowl, large woodpeckers, barbets and cuckoos were detected at larger distances from the observers. As detectability of species also varies depending upon the habitat and seasons, separate detection functions were fitted for each group for different seasons and forests. Appropriate right truncation was used for each group. A detection model was selected after examining the fit of estimated detection function to the data. All densities were calculated as numbers/ha.

6.2.2. Categorization of grids in three different disturbance regimes

For categorizing the sites, within each forest type, in different disturbance categories, non-correlated and ecologically significant disturbance variables (% of lopped trees, number of cut trees and stumps, % of grazing and number of trails) indicating disturbance were then averaged over the nine circular intensive sampling plots established at each grid to give a single value for these grids. Each of these grids was then designated into one of the three disturbance levels (low, medium and high).

6.2.3. Birds as Indicator species of disturbance level

I used indicator species analysis to identify if any bird or species assemblages prefer particular disturbance level. Indicator species analysis is a simple non-parametric technique to examine the specificity of use of the habitats by individual species (Dufrêne & Legendre, 1997). This technique combines a species relative abundance with its relative frequency of occurrence in the various groups of sites. Indicator species are defined as the most characteristic species of each group, found mostly in a single group of the typology and present in the majority of the sites belonging to that group. The method was essentially outlined for abundance data though a modified form was proposed for presence–absence data as well (Dufrêne & Legendre, 1997).The indicator value is calculated as follows:

$$\boldsymbol{Indicator\ value}=\boldsymbol{A_{ij}} \times \boldsymbol{B_{ij}} \times \boldsymbol{100}$$

Where A_{ij} is the mean abundance of species i in the sites of group j compared to all groups in the study and B_{ij} is the relative frequency of occurrence of species i in the sites of group j. B_{ij} is the measure of fidelity of a species. Indicator values (IV) range from 0 to 100 where perfect indication (100) means that the species indicates a particular habitat without error. Randomization tests were used to evaluate the statistical significance of the indicator value, using 1000 randomizations. Indicator values of all the bird species were computed using PC-ORD version 4.20 (McCune & Mefford, 1999).

Pearson correlation was carried out between abundance of selected set of indicator species with different disturbances to identify species indicating particular disturbance factors. Correlations were carried out at grid level to avoid the problem of spatial autocorrelation among the intensive sampling points.

6.2.4. Refining indicator list using selection criteria

As I identified indicators of small-scale extractive disturbances, I chose parameters that increase the usefulness of selected indicators for monitoring habitat degradation. Therefore, out of a large set of desirable attributes mentioned in various studies, four important parameters i.e., detectability, seasonal availability, occurrence in different forest type and response to disturbance indicators were selected (see Table 6.1). All parameters were ranked on a scale of 0 to 1.

Table 6.1.: Attributes of indicator species selected for refining the indicator list in this study for monitoring small-scale extractive disturbances

Parameter	**Justification**	**References**
Detectability	Ease of detection and mensuration helps in inexpensive monitoring	(Noss, 1990; Pearson & Cassola, 1992; Hilty & Merenlender, 2000)
Seasonal availability	(1) Resident species could be monitored throughout the year (2) changes in attributes of migrants species could also operate outside the target area.	(Bock & Webb, 1984; Landres et al., 1988; Hilty & Merenlender, 2000)
Occurrence	Widespread occurrence helps in monitoring of multiple sites using single indicator.	(Noss, 1990; Landres et al., 1988; Pearson & Cassola, 1992)
Response to multiple stressors	An indicator species responding to multiple stressors has more utility to one which responds to only one stressor.	(Noss, 1990; O'Connell et al., 2000)

The first desirable attribute of indicators was ease of detection and for that I used average detection distance which is a function of their detection by sight and aural cues. For calculating detectability, species were categorized into three groups based on their detection behavior. Birds with higher detection probability either due to their call or size or any other peculiar behavior such as hornbills, jungle fowl, received a rank of 1 whereas birds with moderate detection probability such as mynas, bulbuls, bushchats were given a rank of 0.66 and birds with lowest detection such as prinias, tits, wablers were assigned a rank of 0.33.

Birds were differentiated into two categories depending upon their year round availability in the study area. Species which are found throughout the year were considered as resident and others as migrant. Resident birds were ranked as 1 and migrants as 0.5. Another parameter was distribution among forest type so birds found in all forest type were ranked as 1 and the one restricted to one particular forest type was ranked as (1/3=0.33).

An important quality of indicators for this study was their sensitivity to disturbances. Pearson's correlation was carried out between densities of selected set of indicator species with four different disturbances (lopping, grazing, firewood collection and timber extraction). Densities were calculated separately for breeding and non-breeding season. Correlations and density estimation were carried out at grid level to avoid the problem of correlation among intensive sampling points within a grid. All positive responses of birds with disturbance variables were separated from negative ones. These effect sizes (correlation coefficient=r) were then converted into ranks and totaled to get a final value. It yielded two variables correlation rank for the birds with positive and negative responses to the disturbance.

As all the attributes varied in their significance therefore we gave weights to all the parameters of indicator species based on expert opinion. I considered sensitivity to disturbance as the most desirable attribute of indicator therefore gave a weight of 1 to it and ease of detection as the next important criteria which obtained a weight of 0.8. Occurrence of indicator among all forest was given a weight of 0.6 and 0.4 to the availability of the species in the target area. Then we multiplied parameter values with their respective weight and calculated the final rank. This was done separately for the species responding positively and negatively to disturbance.

A final list of top indicators with a rank value of more than two was created to make the monitoring task manageable. Species with high rank value for both positive and negative response (e.g., Oriental-pied hornbill, Brown-headed barbet, White-rumped shama etc.) to disturbance were removed the final list of top indicators for easier interpretation of results. Absolute densities of top indicators in high and low disturbance areas as well as season for monitoring are included in the table which can be used as a benchmark. Moreover, intensive sampling points of this study (Appendix 6.1) can be used as control sites and new areas with varying degree of disturbance can be selected for future monitoring program.

6.3. Results

6.3.1. Indicator species for different disturbance level

A total of 66 species of birds emerged as indicators of disturbance in three forests during two seasons. Number of indicator species varied among and within different forest types across seasons. Few indicator species were consistent in their response across forest types such as Rose-ringed Parakeet *Psittacula krameri*, Rufous Treepie *Dendrocitta vagabunda*, Grey-breasted Prinia *Prinia hodgsonii*, Great Tit *Parus cinereus* etc. While others were forest-specific indicators such as Maroon Oriole *Oriolus traillii*, Grey-winged Blackbird *Turdus boulboul* in moist forest and Jungle Prinia *Prinia sylvatica* in hill forest. During breeding season highest number of indicator species with statistical significant ($p < 0.05$) were observed in hill forest 22 (out of 110 total species observed), followed by moist forest 20 (out of 95) and dry forest 15 (out of 102). In non-breeding season highest number of indicator species were recorded from the moist forest (25 out of 87) followed by dry (12 out of 89) and hill (10 out of 90).

Table 6.2.: Indicator species of all forests (only the birds with statistically significant IV shown) arranged in decreasing order of IV for summer.

Disturbance	**Dry Forest**			**Hill Forest**			**Moist Forest**		
	Species	IV	p	Species	IV	p	Species	IV	p
Low	Common Myna	39.9	0.008	Rose-ringed Parakeet	50.3	0.001	Great Tit	47.1	0.001
	Rufous Treepie	35.3	0.016	Purple Sunbird	43.4	0.003	Rose-ringed Parakeet	44.6	0.002
	Emerald Dove	18.5	0.004	Chestnut-shouldered Petronia	42.2	0.03	Blue-throated Flycatcher	30.7	0.02
				Tickell's blue Flycatcher	27.8	0.049	Jungle Myna	30	0.002
				Jungle Prinia	23.3	0.013	Orange-headed Thrush	26	0.02
				Pale-billed Flowerpecker	20.4	0.003	Grey Treepie	18.5	0.004
				Red-billed Blue Magpie	16.2	0.032	Emerald Dove	11.1	0.05
				White-crested Laughing-thrush	13.7	0.02			
Medium	White-rumped Shama	32.3	0.002	Plum-headed Parakeet	39.2	0.02	White-rumped Shama	43	0.001
				Black-headed Cuckooshrike	29	0.006	Bar-winged Flycatcher-shrike	25.1	0.02
				Large Cuckooshrike	17.4	0.009	Red Junglefowl	20.3	0.05
				Black-chinned Babbler	16.6	0.06	Thick-billed Flowerpecker	18.4	0.002
				Oriental-pied Hornbill	16	0.02	Brown-headed Barbet	11.1	0.05
				Brown-headed Barbet	11.1	0.03			
High	Chestnut-shouldered Petronia	47.2	0.001	Spotted Dove	43.4	0.001	Common Myna	40.1	0.001
	Rose-ringed Parakeet	44.5	0.008	Indian Pitta	36.1	0.004	Jungle Crow	35.9	0.009
	Jungle Babbler	42.1	0.001	Rufous Treepie	34.2	0.005	Jungle Babbler	33	0.06
	Grey-breasted Prinia	41.5	0.05	Jungle Babbler	30.7	0.009	Spotted Dove	31.8	0.005
	Spotted Dove	34.9	0.04	Chestnut-bellied Nuthatch	24.5	0.01	Common Tailorbird	27.4	0.003
	Jungle Crow	29.9	0.011	Pied Bushchat	22.8	0.05	Shikra	19.4	0.004
	Green Bee-eater	25.3	0.012	Eurassian-collared Dove	21.6	0.03	White-browed Fantail	17.1	0.02
	Eurassian-collared Dove	22.2	0.02	Black-rumped flameback woodpecker	19.9	0.005	Drongo Cuckoo	14.4	0.04
	Brahminy Starling	20.5	0.02						
	Golden Oriole	16.1	0.05						
	Jungle Myna	11.1	0.05						

Table 6.3.: Indicator species of all forests (only the birds with statistically significant IV shown) arranged in decreasing order of IV for winter.

Disturbance	**Dry Forest**			**Hill Forest**			**Moist Forest**		
	Species	IV	p	Species	IV	p	Species	IV	p
Low	Rose-ringed Parakeet	45.8	0.008	Hume's Leaf-warbler	50	0.001	Great Tit	51.6	0.001
	Velvet-fronted Nuthatch	23.5	0.001	Striated Prinia	23	0.006	Chestnut-bellied Nuthatch	40.2	0.008
				Red Junglefowl	20.5	0.03	Gray-capped Pygmy woodpecker	39.7	0.004
							Rose-ringed Parakeet	35.6	0.05
							Bar-winged Flycatcher-shrike	23	0.01
							Streak-thraoted Woodpecker	20.9	0.003
							Greater-flameback Woodpecker	20.2	0.05
Medium	Oriental White-eye	66.3	0.001	Greater-flameback Woodpecker	22.3	0.005	Rufous Treepie	34.2	0.03
	Hume's warbler	50.4	0.001	Red-billed Blue Magpie	16.4	0.03	Grey-winged Blackbird	22.2	0.001
	Great tit	47.7	0.005				Thick-billed Flowerpecker	22.2	0.001
	Grey-headed Canary Flycatcher	44.8	0.001				White-rumped Shama	22.2	0.004
	White-throated Fantail	28.8	0.01				Maroon Oriole	22.2	0.02
	White-bellied Drongo	27.6	0.05				Red-billed Blue Magpie	21.6	0.02
	Oriental-pied Hornbill	19.2	0.04				White-crested Laughing-thrush	22.2	0.02
							Red Junglefowl	19	0.05
							TickellâĂŹs blue Flycatcher	14.7	0.01
							Oriental-pied Hornbill	14.5	0.03
High	Grey bushchat	33.3	0.001	Slaty-blue Flycatcher	57.9	0.001	Grey Bushchat	44.4	0.001
	Himalayan Bulbul	31.4	0.03	Gray-breasted Prinia	41.1	0.005	Grey-breasted Prinia	32.4	0.03
	Olive-backed pipit	20.6	0.01	Himalayan Bulbul	40.9	0.03	Red vented Bulbul	22.7	0.02
				White-throated Fantail	40	0.002	Common Tailorbird	18.4	0.02
				Gray Bushchat	29.6	0.002	Dusky Warbler	16.7	0.01
							Lemon-rumped Warbler	14.4	0.04
							Olive-backed Pipit	13.9	0.01

Few indicators species were consistent in their response towards disturbance across forest types during breeding season. For instance, Common Tailorbird *Orthotomus sutorius*, Jungle Babbler *Turdoides striata*, Eurasian-collared Dove *Streptopelia decaocto*, Spotted Dove *Streptopelia chinensis* and Jungle Crow *Corvus macrorhynchos* unanimously indicated high disturbance during breeding season. Whereas Great Tit *Parus cinereus* and Velvet-fronted Nuthatch *Sitta frontalis* indicated low disturbance in dry and moist forest. Bird species indicating moderate disturbance were White-rumped Shama *Copsychus malabaricus* in dry and moist forest and Brown-headed Barbet *Megalaima zeylanica* in hill and moist forest (Table 6.2). Emerald Dove *Chalcophaps indica* indicated least disturbed areas in dry and moist forest (Table 6.2).

During non-breeding season, Rose-ringed Parakeet *Psittacula krameri* was strongly associated with the least disturbed areas in dry and moist forest (Table 6.3). Similarly Oriental-pied Hornbill *Anthracoceros albirostris* turned out to be an indicator of moderate disturbance in dry and moist forest whereas Olive-backed Pipit *Anthus hodgsoni* indicated high disturbance areas in these two forest types. Grey Buschat *Saxicola ferreus* consistently indicated high disturbance among all forest types.

6.3.2. Indicators of individual disturbances

In dry forest, during breeding season, Jungle Babbler *Turdoides striata* showed a strong positive relationship with lopping (r = 0.82** ; see Table 6.4). Grey-breasted Prinia *Prinia hodgsonii* was positively associated with firewood collection (r = 0.72*). Rose-ringed Parakeet *Psittacula krameri* showed a negative relationship with timber extraction. During non-breeding season, Velvet-fronted Nuthatch *Sitta frontalis* negatively related with firewood collection (r = -0.68*). Himalayan Bulbul *Pycnonotus leucogenys* and Red-vented Bulbul *Pycnonotus cafer* showed significant positive association with lopping.

In hill forest, three species (Rufous treepie *Dendrocitta vagabunda*, Pied buschat *Saxicola caprata* and Indian pitta *Pitta brachyura*) had a strong positive association with timber extraction. Jungle prinia *Prinia sylvatica* had a strong negative relationship with grazing (r = -0.72*). During non-breeding season, Slaty-blue Flycatcher *Ficedula tricolor* (r =0.87**), White-browed Fantail *Rhipidura aureola* (r =0.68*) and Blue-capped water Redstart *Phoenicurus caeruleocephala* (r = 0.62*) were positively related to the lopping. Hume's Leaf-warbler *Phylloscopus humei*, a winter migratory warbler species, showed a negative relationship

Table 6.4.: Pearson's correlation between Indicator species and disturbance variables for two seasons across three forest types. ** Correlation significant at p<0.01, * p <0.05, N = 10. Relationships close to significant are indicated in bold italics.

Season	**Forest**	**Species**	**Disturbance**			
			Lopping	Firewood collection	Timber extraction	Grazing
Summer	**Dry**	Rufous Treepie	-0.04	-0.35	0.27	***-0.57***
		Chestnut-shouldered Petronia	0.34	***0.58***	-0.43	0.38
		Rose-ringed Parakeet	0.12	**0.64***	***-0.56***	0.25
		Jungle Babbler	**0.82****	***0.52***	-0.01	***0.57***
		Grey-breasted Prinia	0.01	**0.72***	-0.38	0.35
		Spotted Dove	0.36	***0.51***	-0.22	0.26
		Jungle Crow	0.43	***0.61***	-0.21	0.45
	Hill	Rufous Treepie	***0.55***	***0.50***	**0.62***	**0.83****
		Jungle Prinia	***-0.50***	-0.49	***-0.61***	**-0.72***
		Indian Pitta	0.39	0.45	***0.62****	***0.57***
		Pied Bushchat	**0.71***	0.40	**0.70***	***0.52***
	Moist	Great Tit	-0.36	**-0.65***	-0.22	***-0.58***
		White-rumped Shama	-0.37	-0.20	***0.55***	-0.39
		Spotted Dove	***0.54***	-0.06	-0.26	0.40
		Common Tailorbird	***0.51***	-0.30	0.07	0.35
Winter	**Dry**	Velve-fronted Nuthatch	-0.39	**-0.68***	0.10	**-0.76****
		Himalayan Bulbul	**0.80****	-0.03	0.21	0.23
		Red-vented Bulbul	**0.77****	-0.01	0.16	0.14
		White-bellied Drongo	-0.17	-0.40	**0.65***	-0.05
	Hill	Hume's Leaf-warbler	-0.33	-0.16	**-0.61***	-0.39
		Slaty-blue Flycatcher	**0.87****	0.21	***0.56***	0.46
		Striated Prinia	-0.42	-0.33	-0.31	***-0.55***
		Red Junglefowl	-0.41	-0.39	-0.33	***-0.60***
		Common Tailorbird	0.34	0.19	***0.55***	***0.59***
		White-throated Fantail	**0.68***	0.39	0.26	**0.63***
		Blue-capped Redstart	**0.62***	-0.03	0.20	***0.54***
		Fulvous-breasted Woodpcker	0.37	**0.64***	**0.81****	***0.50***
	Moist	Great tit	***-0.50***	***-0.57***	-0.11	**-0.63***
		Rose-ringed Parakeet	-0.16	-0.37	***-0.59***	-0.24
		Grey Bushchat	***0.57***	0.34	-0.24	**0.70***
		Red-billed Blue Magpie	-0.44	-0.10	**0.75***	-0.42
		Maroon Oriole	-0.39	0.32	***0.58***	-0.29
		White-crested Laughing-thrush	***-0.50***	-0.45	-0.07	-0.46

with timber extraction. Red jungle Fowl *Gallus gallus* and Striated Prinia *Prinia crinigera* were negatively related to grazing whereas White-throated Fantail *Rhipidura albicollis*, Common-Tailorbird *Orthotomus sutorius* and Blue-capped water Redstart *Phoenicurus caeruleocephala* (Table 6.4).

In moist forest, Great Tit *Parus cinereus*, an indicator of low disturbance had negative relationship with all disturbance variables especially with firewood collection (r = -0.65*). Common Tailorbird *Orthotomus sutorius* and Spotted Dove *Streptopelia chinensis* were positively related with lopping whereas White-rumped Shama *Copsychus malabaricus* was positively related to timber extraction (Table 6.4). During non-breeding season, White-crested Laughingthrush *Garrulax leucolophus* and Great Tit *Parus cinereus* showed a negative relationship with lopping but Grey Bushchat *Saxicola ferreus* was positively related to it. Red-billed Blue Magpie *Urocissa erythrorhyncha* and Maroon Oriole *Oriolus trailii* showed positive correlation with timber extraction but Rose-ringed Parakeet Psittacula krameri had a negative correlation with it. Great Tit *Parus cinereus* and Grey Bushchat *Saxicola ferreus* were found to be correlated significantly with grazing where the former was negatively related with it and later positively.

6.3.3. Robust indicator of overall disturbance

A total of 55 indicator species were given ranks using selection criteria (Table 6.5). Out of 55 indicators, final rank of 41 species ranged between 1 and 2 and only 18 species had rank 2 or above. Out of 18 top indicators, Oriental-pied Hornbill and White-rumped Shama appeared in the list of species with negative and positive relationship with disturbance and therefore these species were omitted from the final list. Further refinement resulted in a final list of 15 indicator species for potential monitoring of overall disturbance due to extractive practices in this landscape. These top indicators included species with positive (8 species) and negative association (7 species) with disturbance (Table 6.6).

Table 6.5.: Ranking of indicator species for four selected attributes and final weighted average rank of species showing positive and negative response to overall disturbance.

Candidate species	**Detectability**	**Availability**	**Distribution**	**Positive**	**Rank**	**Negative**	**Rank**
Oriental-pied Hornbill	1.00	1.00	1.00	0.34	2.14	0.26	2.06
Bar-winged Flycatcher-shrike	0.33	1.00	1.00	0.07	1.34	0.48	1.75
Large Cuckooshrike	0.67	1.00	1.00	0.02	1.55	0.35	1.88
Common Tailorbird	0.67	1.00	1.00	0.99	2.52	0.00	1.53
Grey-breasted Prinia	0.33	1.00	1.00	0.50	1.77	0.02	1.29
Jungle Prinia	0.67	0.50	0.33	0.00	0.93	0.91	1.84
Striated Prinia	0.33	0.50	0.33	0.00	0.67	0.70	1.37
Eurasian-collared Dove	0.67	1.00	1.00	0.70	2.23	0.00	1.53
Emerald Dove	0.67	1.00	1.00	0.00	1.53	0.36	1.89
Spotted Dove	0.67	1.00	1.00	0.59	2.12	0.00	1.53
Grey Treepie	1.00	1.00	0.33	0.04	1.44	0.20	1.60
Jungle Crow	1.00	1.00	1.00	0.32	2.12	0.10	1.90
Red-billed Blue Magpie	1.00	1.00	1.00	0.10	1.90	0.60	2.40
Rufous Treepie	1.00	1.00	1.00	0.13	1.93	0.14	1.94
Pale-billed Flowerpecker	0.33	1.00	1.00	0.22	1.49	0.48	1.75
White-bellied Drongo	0.33	1.00	1.00	0.57	1.84	0.00	1.27
Brown-headed Barbet	1.00	1.00	1.00	0.33	2.13	0.15	1.95
Green Bee-eater	0.33	1.00	1.00	0.67	1.94	0.00	1.27
Olive-backed Pipit	1.00	0.50	0.67	1.00	2.80	0.00	1.80
Blue-throated Flycatcher	0.33	0.50	1.00	0.00	1.07	0.71	1.78
Grey Bushchat	0.67	0.50	1.00	0.61	1.94	0.11	1.45
Pied Bushchat	0.33	1.00	1.00	0.95	2.22	0.00	1.27
Slaty-blue Flycatcher	0.33	0.50	1.00	0.67	1.74	0.00	1.07

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Table 6.5 – *Continued from previous page*

Candidate species	**Detectability**	**Availability**	**Distribution**	**Positive**	**Rank**	**Negative**	**Rank**
Tickell's blue Flycatcher	0.33	0.50	1.00	0.22	1.29	0.39	1.45
White-rumped Shama	1.00	1.00	1.00	0.30	2.10	0.29	2.09
Purple Sunbird	0.33	1.00	1.00	0.36	1.63	0.06	1.33
Golden Oriole	0.67	0.50	1.00	0.29	1.62	0.00	1.33
Maroon Oriole	0.67	0.50	0.33	0.44	1.37	0.24	1.18
Great Tit	0.33	1.00	1.00	0.00	1.27	1.00	2.27
Chestnut-shouldered Petronia	0.33	0.50	1.00	0.46	1.53	0.04	1.11
Red Junglefowl	1.00	1.00	1.00	0.00	1.80	0.67	2.47
Hume's Leaf-warbler	0.67	0.50	1.00	0.00	1.33	0.60	1.94
Black-rumped Flameback	0.67	1.00	1.00	0.74	2.27	0.00	1.53
Greater flameback Woodpecker	1.00	1.00	1.00	0.02	1.82	0.40	2.20
Streak-throated Woodpecker	1.00	1.00	1.00	0.06	1.86	0.48	2.28
Indian Pitta	0.67	0.50	1.00	0.49	1.82	0.00	1.33
Plum-headed Parakeet	0.67	1.00	1.00	0.01	1.54	0.14	1.68
Rose-ringed Parakeet	0.67	1.00	1.00	0.00	1.53	0.64	2.18
Himalayan Bulbul	0.67	1.00	1.00	0.40	1.93	0.08	1.61
Red-vented Bulbul	0.67	1.00	1.00	0.46	1.99	0.00	1.53
White-throated Fantail	0.67	1.00	1.00	0.33	1.86	0.17	1.71
White-browed Fantail	0.33	1.00	1.00	0.14	1.41	0.19	1.46
Chestnut-bellied Nuthatch	0.67	1.00	1.00	0.14	1.67	0.31	1.84
Velvet-fronted Nuthatch	0.33	1.00	1.00	0.15	1.42	0.55	1.82
Grey-headed Canary-flycatcher	1.00	0.50	1.00	0.11	1.71	0.24	1.84
Brahminy Starling	0.33	1.00	1.00	0.11	1.38	0.23	1.50

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Table 6.5 – *Continued from previous page*

Candidate species	**Detectability**	**Availability**	**Distribution**	**Positive**	**Rank**	**Negative**	**Rank**
Common Myna	0.67	1.00	1.00	0.48	2.01	0.19	1.73
Jungle Myna	0.67	1.00	1.00	0.12	1.65	0.18	1.72
Black-chinned Babbler	0.33	1.00	1.00	0.24	1.51	0.07	1.34
Jungle Babbler	0.67	1.00	1.00	0.45	1.98	0.00	1.53
White-crested laughing thrush	1.00	1.00	1.00	0.00	1.80	0.83	2.63
Grey-winged Blackbird	0.33	0.50	0.33	0.50	1.17	0.14	0.81
Oriental White-eye	0.33	1.00	1.00	0.20	1.47	0.36	1.62

Table 6.6.: Top indicator species across forest types. Species indicated in bold can be used as indicators only during summer season while rest throughout the year.

Response to Disturbance	**Species**	**Weighted Rank**	**Density (Indi/ha)**	
			Low-Disturbance	*High-Disturbance*
Negative	White-crested Laughingthrush	2.63	0.350	0.037
	Red Junglefowl	2.47	0.346	0.159
	Red-billed Blue Magpie	2.40	0.348	0.054
	Streak-throated woodpecker	2.28	0.035	0.037
	Great Tit	2.27	2.722	1.601
	Greater-flameback Woodpecker	2.20	0.064	0.048
	Rose-ringed Parakeet	2.18	2.235	1.525
Positive	Olive-backed Pipit	2.80	0.011	0.085
	Common Tailorbird	2.52	0.12	0.449
	Black-rumped flameback woodpecker	2.27	0.063	0.135
	Large-billed Crow	2.12	0.217	0.281
	Eurasian-collared Dove	2.03	0.029	0.161
	Pied Bushchat	2.02	0.027	0.221
	Common Myna	2.01	0.772	0.892
	Spotted Dove	2.00	0.260	0.685

6.4. Discussion

This chapter supports the utility of birds as indicator of small-extractive disturbances. Birds provide a very inexpensive way of monitoring differentially disturbed areas as well as intensity of different disturbances. The indicator species identified in this study can be utilized to develop a simple and economical protocol which can be utilized by managers to monitor degradation of forest due to small-scale extractive disturbances.

6.4.1. Traits of Indicator species

I identified indicator species for specific extractive disturbances in the study area and sensitivity of these birds towards disturbance could be attributed to their ecological traits. For example, Red jungle Fowl *Gallus gallus*, Jungle Prinia *Prinia sylvatica* and Striated Prinia *Prinia crinigera* nest on or near to ground. And all these species in the hill forest, decreased in abundance with increasing grazing pressure. Hill forest in particular experiences intensive grazing, bhabar grass collection and fire during breeding season. Moreover, such disturbance could have severe implication especially for habitat specific species such Jungle Prinia *Prinia sylvatica* which is distributed only in hill forest. Jansen et al. (1999) also found a negative relationship of a grassland species, Grey-wing Francolin *Francolinus levaillantii* decreased with increasing grazing and burning highlands of South Africa.

In the study area, all forest types are experiencing firewood collection but moist forest in particular faces heavy lopping of twigs, branches and bark from the live trees. Great Tit *Parus cinereus*, Velvet-fronted Nuthatch *Sitta frontalis* were two such species which decreased in abundance with increasing firewood collection. Both these species are specialized in foraging technique as they prey on the insects mainly available in bark of tertiary branches and trunk. Great Tit *Parus cinereus* in particular is an excellent indicator of firewood collection as it is consistent in its response across seasons. This result is in consent with a study from eastern Himalaya where bark-gleaners preferred areas with low-firewood collection (Laiolo, 2004).

Timber extraction directly results in decreased nesting options for cavity nesting birds and indirectly by modifying stand composition as past management created patches of small girth trees unsuitable for cavity making by large bodied birds such as Parakeet, Hornbills, Barbets and Woodpeckers. Rose-ringed Parakeet *Psittacula krameri*, a cavity nesting bird, showed a negative relationship with timber extraction in Sal *Shorea robusta* dominated dry and moist forest. Even, Common Myna *Acridotheres tristis* a species generalist in food demands, nests in tree cavities and it also turned out be an indicator of timber extraction in dry forest during breeding season.

6.4.2. Disturbance mediated biotic homogenization

Generalist species often specialize in utilizing more resources fairly and perform well in unstable or heterogeneous environment. While specialist species trade-off in utilizing few resources well and therefore favoured by stable or homogeneous environment. While utilizing the data on 105 common bird species of the French Breeding Bird Survey (895 spatial replicates), Devictor et al. (2008) examined the spatial variation in abundance of these birds against fragmentation and disturbance. They developed a species specialization index (SSI) in which species with high variation across habitat type was considered a specialist whereas the one with little variation as generalist. In their study, specialized birds had a negative response to fragmentation as well as disturbance. Soh et al. (2006) found that highly modified urban areas were marked by the presence of few generalist species and preferred by less resilient montane bird species. In another study, Chettri et al.Chettri et al. (2001) also found abundance of habitat generalist species to be more abundant near human settlement than inside the forest. Shahabuddin & Kumar (2006) in scrub forest of Sariska also found that extractive disturbance positively influenced Laughing Dove *Streptopelia senegalensis*, a generalist species, whereas specialist species such as Great Tit *Parus cinereus* and White-browed Fantail *Rhipidura aureola* were adversely affected.

Findings of my study are in consensus with above mentioned studies. In my study, highly disturbed areas across forest types were preferred by generalist species whereas specialist species preferred less disturbed habitats. For example, Jungle Babbler *Turdoides striata*, Spotted Dove *Streptopelia chinensis*, Jungle Crow *Corvus macrorhynchos* are generalist in food demands (Ali et al., 1995; Grimmett et al., 1999) and therefore emerged as indicator of high disturbance in the study area. Species specialized in their breeding (e.g. cavity nesting) or feeding (e.g. trunk-bark feeder) demands, preferred less disturbed areas in all forests.

Despite of significant differences in vegetation characteristics of three forest types in our study and bird composition (figure) disturbed areas are represented by similar assemblages of generalist species such as Jungle Babbler *Turdoides striata*, Spotted Dove *Streptopelia chinensis*, Jungle Crow *Corvus macrorhynchos*. This trend of increasing similarity among biotic communities due to invasion, disturbance or developmental process is known as biotic homogenization (McKinney & Lockwood, 1999). Studies across different taxa are also showing similar results where generalist species are less negatively affected by disturbance or rather favoured by unstable environments. Canopy opening and concomitant grazing in the ground layer across all forest types in our study led to invasion of an exotic shrub, *L.camara*. This disturbance induced lantana invasion appears to be a major reason of biotic homogenization in our study area. Species such as Slaty-blue Flyacatcher *Ficedula tricolor* (R^2=0.76, $p<0.001$), Himalayan Bulbul *Pycnonotus leucogenys* (R^2= 0.40, $p=0.05$), Red-vented Bulbul *Pycnonotus cafer* (R^2=0.45, $p=0.04$) and Pied Bushchat *Saxicola caprata* (R^2=0.93, $p<0.001$), in dry and hill forest showed strong positive relationship with *L.camara* cover. A study conducted in southern India also found that *L.camara* positively influencing few generalist species and leading to increased evenness in the bird community (Aravind et al., 2010).

6.4.3. Resident *vs* Migrant

Migrants species are generally considered subordinate to resident and due to their high abundance in secondary habitats are believed to indicators of disturbed areas (Powell, 1980; Rappole & McDonald, 1994). Few past studies have suggested that migrants are more flexible than residents in their habitat use and thus potentially more tolerant of disturbance (Karr, 1976a; Hutto, 1989; Greenberg, 1995). However Terborgh (1989) emphasized that migrants are not weedy opportunists in the tropical forest but an integral part of the overall bird community. Recent studies also supports Terborgh's view and have shown similar response of migrant and resident species (Petit et al., 1992; Wallace et al., 1996; Smith et al., 2001). In our study, migrants preferring less disturbed areas were canopy and understory insectivorous birds such as Hume's Leaf-warbler *Phylloscopus humei*, Tickell's blue Flycatcher *Cyornis tickelliae* and Blue-throated Flycatcher *Cyornis rubeculoides*. Migrant species which indicated highly disturbed areas were all shrub or ground foragers (e.g. Grey Bushchat *Saxicola ferreus*, Slaty-blue Flycatcher *Ficedula tricolor* and Indian Pitta *Pitta brachyura*).

CHAPTER 7

Conclusion

7.1. Small-scale extractive disturbances in Shiwalik landscape

The three forest type in this study differed in their disturbance regimes. These differences were attributed to level of legal protection to forest types and availability of fodder species. Both dry and hill forest had higher availability of fodder trees than moist and thereby they experienced higher grazing and lopping. On the other hand, disturbances such as timber extraction and firewood collection were associated with protection level and therefore were higher in legally less protected moist forest than dry and hill forest types in highly protected Rajaji National Park. Less stringent protection in moist forest made it easier to harvest timber for local agricultural and household needs.

Gradual biomass extraction by local villagers and Gujjar community has resulted in modification in vegetation structure and composition in Shiwalik landscape. Disturbance affected vegetation structure at tree and shrub layers irrespective of the forest type. Structural variables sensitive to disturbances were (a) canopy cover, which decreased with lopping pressure; and (b) shrub height, which decreased with livestock grazing pressure, in all three forest types. Moreover, cover of native shrub species also declined with extractive disturbances. Canopy opening and reduced shrub cover is expected to increase dry condition as more sunlight will reach the soil layer.

Until 2003, entire study area had been utilized by villagers and Gujjars. This is short a period to observe any change in tree composition but shrub composition has altered considerably. However, the relationship of canopy and understory is dynamic and interdependent, therefore a shift in tree species composition can also be expected in future (Foré et al., 1997).

Selective lopping of species in dry and hill forests might pose a threat to the overall tree diversity in this region. In Rajaji National Park, long-term lopping of fodder trees such as *Terminalia belerica*, *Terminalia tomentosa*, *Anogeissus latifolia Zizyphus xylopyra* and *Bridelia retusa* had possibly interfered with their regeneration process, leading to their fewer individuals in smaller GBH classes. Moreover, Gujjars have started harvesting less palatable tree species due to declining densities of preferred fodder trees resulting in more disturbance.

Effects of similar disturbances could vary depending upon the forest characteristics. For instance, in the present study, large scale disturbance due to timber extraction in the past was responsible for the presence (invasion) of *L. camara* in dry forests but not in moist forest. This could be attributed to more canopy cover and soil moisture in moist forest than other two forest types. Also *L. camara* performed well at moderate level of canopy closure as higher disturbance leading to decrease in canopy cover in dry forests reduced its abundance. Small-scale extractive practices such as livestock-grazing and lopping, facilitated *L. camara* abundance in dry forest. Such invasion is detrimental to native vegetation diversity as established by various studies (Fensham et al., 1994; Sharma et al., 2006; Gooden et al., 2009).

7.2. Impact of disturbance on bird community and guild

Small-extractive disturbances could influence the faunal community directly or indirectly by modifying habitat characteristics such as canopy cover, resource availability etc. Therefore, I investigated the role of habitat disturbance as well as vegetation attributes on important parameters of bird community viz., richness, density and composition.

Modification in vegetation structure and invasion of exotic invasive shrub *L. camara* is the major disturbance induced change in the study area. *L. camara* in particular emerged as an important variable influencing bird community parameters. However, only particular guilds (nectarivore, fruit-seed-insectivore and omnivore) were benefited by the year round availability of *L.camara* fruit and flower resources. Strong association of some understory (Slaty-blue Flycatcher, Himalayan Bulbul, Red-vented Bulbul) with *L.camara* could be explained by its dense thickets, that provides safe foraging and nesting opportunities.

Within a given area increasing habitat heterogeneity has been long proved to enhance species richness by providing more niches. Coefficient of variation of tree crown cover, an index of canopy patchiness, has also been found promoting species richness in my study.

One of the immediate effects of most of the disturbances is canopy opening. In our study forests which had closed canopy such events led to increase in prey visibility for birds and thereby elevated species richness.

7.3. Avian Indicators of small-scale extractive disturbances

In this study, highly disturbed areas were indicated by generalist species whereas specialist species indicated less disturbed habitats. This trend agrees with similar studies inspecting effect of disturbance on birds in different forest types (Shahabuddin et al., 2006; Soh et al., 2006). Generalist species often specialize in utilizing diverse resources and perform well in unstable or heterogeneous environment. While specialist species trade-off in utilizing few resources well and therefore favoured by stable or homogeneous environment.

Indicators of specific disturbances were largely the bird species directly dependent on a particular resource. For example, bird species foraging and nesting on ground/understorey such as Red Junglefowl, Jungle Prinia, Striated Prinia were negatively related to grazing. Similarly, decreasing density of small-sized trunk-bark foraging bird species such as Great Tit and nuthatches declined with firewood collection. Birds dependent on tree cavities during breeding season were negatively influenced by timber extraction which is usually restricted to large sized trees and emerged as excellent indicators for this disturbance. This study supports the utility of birds as indicator of small-extractive disturbances. Birds provide a very convenient way of monitoring differentially disturbed areas as well as intensity of different disturbances. In the present study a large set of bird species were identified, each having a potential to be used as an indicator of small-scale extractive disturbances but later on utilizing a selection criteria, a smaller set of higher utility indicators were also identified. The managers based on their requirement and resources can choose from this set to monitor small-scale extractive disturbances in the Shiwalik landscape.

7.4. Direction for future research

The present study was replicated in three forest types significantly differing in vegetation structure and composition and it revealed that some effects of small-scale extractive disturbance were similar but other differed according to the forest type. This finding stresses on the need for more such studies from different forest types and biogeographic regions to draw generalization and conclusion about their effect. Further, with increase in human density and consequent increase in pressures over forest for biomass it becomes important to estimate permissible limits for biomass extraction to identify and promote new livelihood options for the forest dependent communities.

The present study assessed the influence of forest fires based on recent fire events only. With the use of remote sensing techniques it is now possible to get quality information on the history, extent, intensity and frequency of fire which might have strong association with other small-scale extractive disturbances. Influence of these disturbances on the survival and regeneration of the heavily exploited tree species is another important area of future research which may help us come up with rules regulating lopping, grazing and other disturbances based on scientific information.

An important finding of this study was the identification of causative disturbance agents for presence and abundance *L. camara*. A self-perpetuating fire–*L. camara* cycle has already been established for the Bilgiri Rangaswamy Temple Wildlife Sanctuary, Western Ghats, where invasion was followed by the fire incident. Therefore, an important ecological inquiry is to investigate the role of fire in facilitating *L.camara* in the study area. Additionally effect of *L. camara* on native shrub and tree regeneration needs an urgent attention with more and more area getting invaded.

In this study, the effects of small-scale extractive disturbances were investigated at the community and foraging guild level. Birds should be categorized based on different ecological and life history traits to examine the response of particular species on various dimensions of its niche. Moreover, effect of disturbance should also be investigated at population level by radio-tagging birds in differentially disturbed areas and examine their habitat use and home range sizes with respect to disturbance.

Indicator species identified in this study also need to be verified by selecting spatial replicates in different forest types and different disturbance levels to assess their accuracy and sensitivity towards small-scale extractive disturbances. Moreover, an important area of investigation is to examine the congruency among indicator birds and other animal taxa.

APPENDIX A

Table A.1.: Correlation matrix between disturbance and vegetation structural variables for three forests. Statistically significant correlations between disturbance and tree layer structural variables are indicated (*=p<0.05 and **=p<0.01).

Forest Type	Disturbance	Tree basal area	Tree crown cover	Canopy cover %	Tree density	Shrub density	Shrub height	Shrub cover	Lantana cover
Dry Forest	Lopping	-0.27	-0.19	-0.36	0.21	-0.17	0.14	-0.11	0.59
	Firewood collection	-0.03	-0.44	-0.77**	-0.05	0.34	-0.84**	-0.76*	-0.09
	Timber extraction	-0.19	-0.02	0.14	0.36	0.04	0.34	0.35	0.47
	Grazing	-0.14	-0.54	-0.68*	0.17	0.48	-0.77**	-0.72*	0.17
Hill Forest	Lopping	-0.45	-0.78**	-0.85**	0.13	-0.02	-0.75*	-0.42	0.67*
	Firewood collection	-0.28	-0.62	-0.34	0.44	-0.12	-0.13	0.31	0.32
	Timber extraction	-0.18	-0.58	-0.34	0.85**	-0.32	-0.03	-0.17	0.67*
	Grazing	-0.22	-0.87**	-0.80**	0.37	0.24	-0.57	-0.26	0.51
Moist Forest	Lopping	0.07	-0.41	-0.90**	-0.47	0.82**	-0.64*	-0.34	-0.04
	Firewood collection	-0.17	-0.38	-0.33	0.07	0.70*	-0.55	-0.39	-0.21
	Timber extraction	-0.54	-0.31	-0.07	0.61	0.09	0.03	-0.18	-0.16
	Grazing	-0.07	-0.58	-0.74*	-0.35	0.81**	-0.73*	-0.32	-0.15

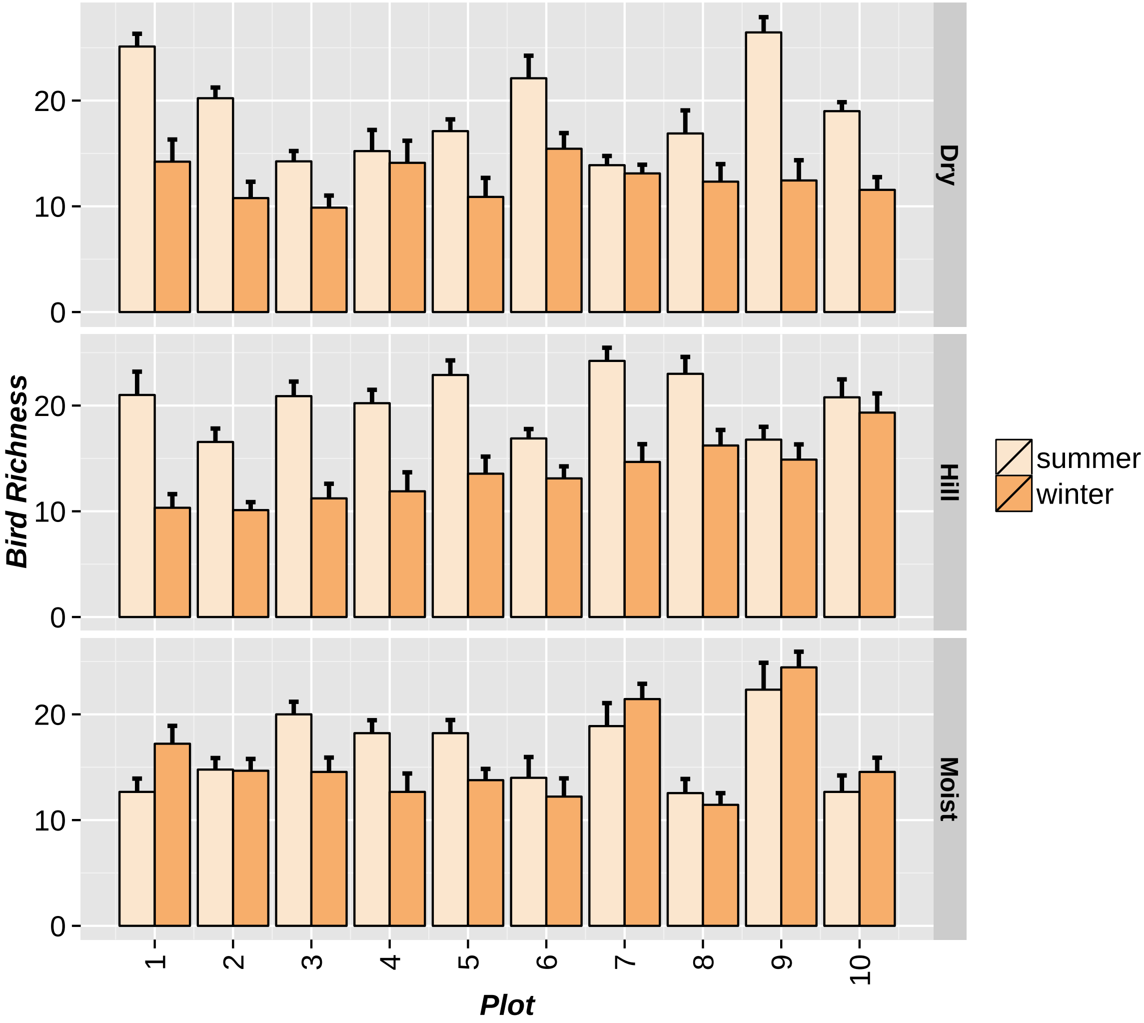
APPENDIX B

Table B.1.: Estimated bird species richness and diversity for each plot of all the forest types for summer and winter season.

Forest Type	Grid Name	Summer			Winter		
		S_{obs}	Richness (Jacknife 1)	Diversity H'	S_{obs}	Richness (Jacknife 1)	Diversity H'
Dry	Andheri	54	73.56	3.25	44	59.11	2.65
Dry	Bam	64	81.5	3.26	50	64	2.87
Dry	Beenj	38	64	2.89	28	37.78	2.54
Dry	Chilawali	57	76.56	3.47	52	68.89	3.15
Dry	Dholkhand	52	67.11	3.26	40	53.33	2.8
Dry	Ganjarban	54	71.78	3.29	38	52.22	2.88
Dry	Kaniya	50	66	3.29	39	55	2.66
Dry	Lakarkot	64	80	3.4	47	61.22	2.83
Dry	Shikaribada	61	70.78	3.26	53	68.11	3.17
Dry	Sukh	43	56.33	3.22	38	50.44	2.82
Hill	Andherib	65	78.33	3.46	52	70.67	3.11
Hill	Andherinew	53	63.67	3.32	44	57.33	2.97
Hill	Anicut	56	67.56	3.33	44	56.44	2.99
Hill	Bamb	56	67.56	3.2	46	64.67	3.15
Hill	Chilawalib	61	76.11	3.31	49	65.89	2.99
Hill	Dholkhandb	64	81.78	3.37	45	55.67	2.82
Hill	Khajnawar	48	63.11	3.06	45	56.56	2.96
Hill	Kharasot	58	74	3.49	49	60.56	3.04
Hill	Sukhb	48	61.33	3.28	43	56.33	3.03
Hill	Tigernala	50	70.44	3.22	33	43.67	2.88
Moist	Asarori	49	63.22	3.1	37	44.11	3.17
Moist	Bulindawala	48	61.33	3.15	40	48	2.65
Moist	Dharmawala	53	69.89	3.08	37	47.67	2.84
Moist	Kaluwala	40	55.11	2.93	34	42	2.82
Moist	Kansrao	49	64.78	3.28	47	63.22	3.16
Moist	Karwapani	38	50.44	2.97	38	50.44	2.97
Moist	Laldhang	41	49.89	2.54	41	49.89	2.54
Moist	Malhan	60	75.11	3.24	51	67.89	2.9
Moist	Sabbawala	39	47	2.78	39	47	2.78
Moist	Timli	54.00	67.33	3.20	42	53.56	2.80

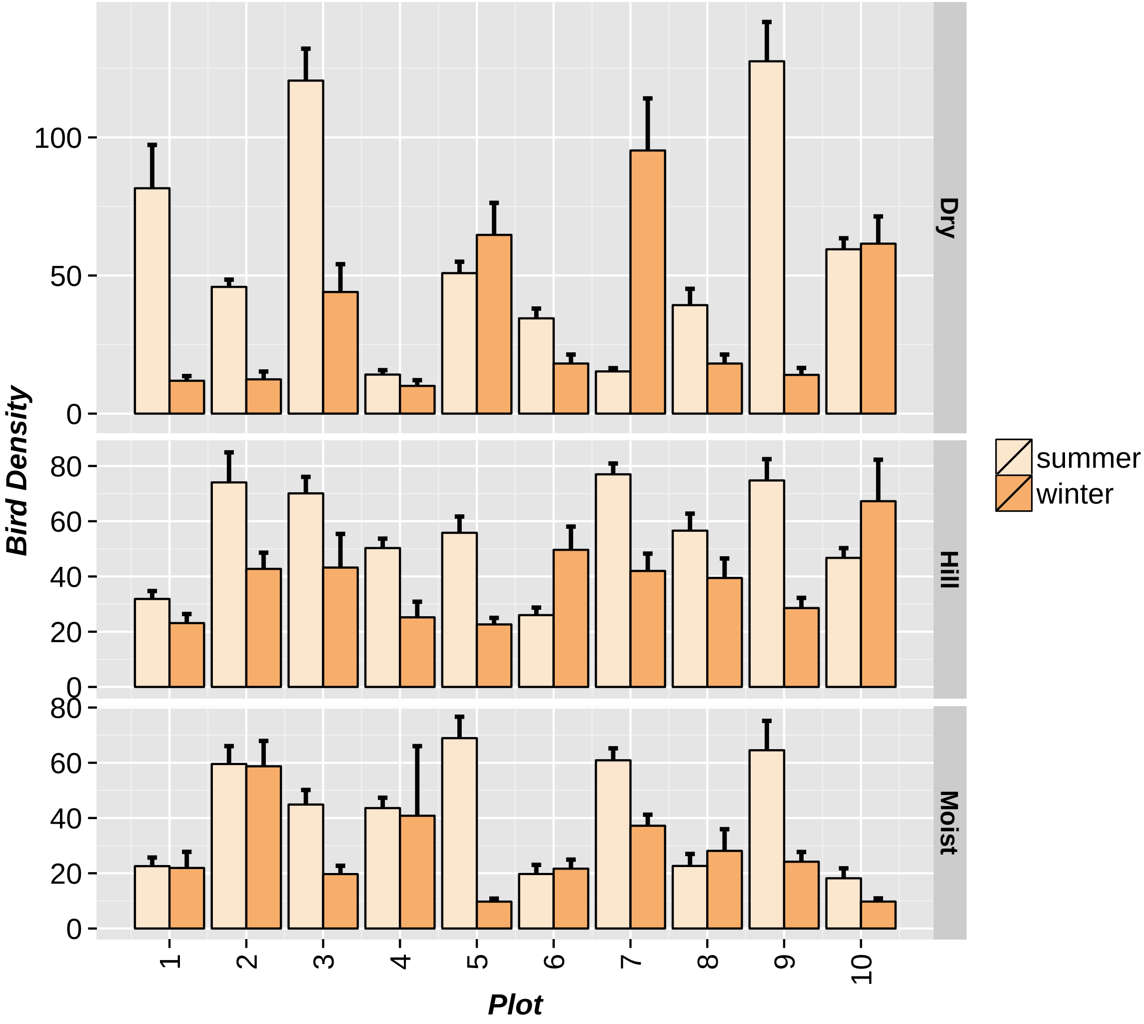
APPENDIX C

Figure C.1.: Bird species richness (Mean±SD; number of species averaged across sampling points) for breeding and non-breeding season across disturbance gradient in all forest types



APPENDIX D

Figure D.1.: Mean bird densities (Mean±% CV; number of individual per hectare averaged across sampling points) for breeding and non-breeding season across disturbance gradient in all forest types.



APPENDIX E

Summary statistics [Akaike Information Criteria (AICc) and relative support for hypothesis (Δ AICc) of candidate models explaining variation in bird guild density in **Dry forest** as a function of vegetation, disturbance and invasive cover during (a) breeding and (b) non-breeding season of 2009–11

Guild	**SUMMER**			**WINTER**		
	Model description	AICc	Δ AICc	Model description	AICc	Δ AICc
Canopy Insectivore	Tree diversity+% canopy cover	222.09	0.00	Tree diversity+ Tree basal area	214.99	0
	Tree diversity+ Tree basal area	224.1	2.01	Tree basal area+ Tree crown cover	217.64	2.65
	Tree basal area+ Tree crown cover	227.12	5.03	Lopping+ Firewood collection	218.86	3.87
	Lopping+ Firewood collection	229.26	7.17			
Understory-Insectivore	Timber extraction+ Lopping+% canopy cover	261.56	0.00	Shrub diversity+ Lopping+% canopy cover	321.95	0
	% canopy cover+ Lantana density	264.8	3.24	% canopy cover+ Lantana density	324.55	2.6
	Shrub diversity+ Tree diversity	264.83	3.27	Lantana density +shrub volume	330.11	8.16
	Timber extraction+ Grazing+ Lopping+ Firewood collection	267.09	5.53	Shrub volume+ lantana cover	330.45	8.5
	Lantana density+ Shrub volume	269.78	8.22	Timber extraction +Grazing+ Lopping +Firewood collection	333.63	11.68
Sallying Insectivore	Lantana density+ Shrub diversity+% canopy cover	214.29	0.00	Tree density+ Tree diversity	137.59	0

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Table E.1 – *Continued from previous page*

Guild	**SUMMER**			**WINTER**		
	Model	AICc	Δ AICc	Model	AICc	Δ AICc
	Timber extraction+ Lopping+ Fire	218.73	4.45	Lantana density+ Shrub diversity+% canopy cover	142.69	5.1
	Tree density+ Tree diversity	221.97	7.68	Timber extraction +Lopping+ Fire	145.93	8.34
Trunk-bark feeder	Fire+ Tree diversity	194.71	0.00	Tree density+ Tree basal area	191.3	0
	Tree density+ Tree diversity	199.16	4.45	Tree density+ Tree diversity	199.26	7.96
	Tree crown cover+% canopy cover+ Tree basal area	203.65	8.94	Tree crown cover+% canopy cover+ Tree basal area	199.56	8.26
	Timber extraction+ Lopping+ Fire	203.7	8.99	Timber extraction+ Lopping+ Fire	207.6	16.3
Frugivore	Shrub diversity+ Lopping	128.26	0.00	% canopy cover+ Tree diversity	94.61	0
	Timber extraction+ Lopping+ Fire	135.25	6.99	shrub diversity+ Tree diversity	97.34	2.73
	% canopy cover+ Lantana density+ Tree basal area	137.98	9.72	Timber extraction+ Lopping+ Fire	102.98	8.37
				% canopy cover+ Tree basal area+ Lantana density	103.99	9.38
Fruit Seed Nectar Insectivore	Firewood collection+% canopy cover	260.59	0.00	Tree diversity+ Shrub diversity	224.39	0

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Table E.1 – *Continued from previous page*

Guild	**SUMMER**			**WINTER**		
	Model	AICc	Δ AICc	Model	AICc	Δ AICc
	Tree diversity +Shrub diversity	265.35	4.76	Lopping+ Firewood collection	228.09	3.7
	Firewood collection+ Fire+ Lopping	265.63	5.04	Lantana cover+ shrub volume	228.81	4.42
	Lantana density+ Tree density	269.39	8.80	Lopping+ Firewood collection+ Tree diversity	234.51	10.12
Omnivore	% canopy cover+ shrub diversity	155.15	0.00	Tree diversity	64.99	0
	Tree basal area+ Tree density	160.82	5.67	Tree diversity+ Tree crown cover	68.44	3.45
	shrub volume+% canopy cover+ Lantana density	164.09	8.94	Tree density+% canopy cover+ Tree crown cover	77.13	12.14
	Lopping+ Fire+ Firewood collection+ Grazing	165.21	10.06	Firewood collection+ Timber extraction	78.95	13.96
Granivore	% canopy cover	178.75	0.00			
	Lantana density+ Tree density	190.31	11.56			
	Timber extraction+ fire+ Lopping+ Grazing	197.45	18.70			
Nectar-Insectivore	Grazing+ Tree diversity	195.29	0.00	Shrub diversity+ Tree diversity	250.59	0

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Table E.1 – *Continued from previous page*

Guild	**SUMMER**			**WINTER**		
	Model	AICc	Δ AICc	Model	AICc	Δ AICc
	shrub diversity+ Lantana cover	199.7	4.41	Lopping+ Fire+ Tree diversity	252.8	2.21
	Lantana cover+% canopy cover	201.44	6.15	Lantana cover+ Shrub volume+ Tree crown cover	254.02	3.43
	Lopping+ Grazing+ Fire	201.69	6.40	Lopping+ Fire+ Timber extraction	254.23	3.64

APPENDIX F

Summary statistics [Akaike Information Criteria (AICc) and relative support for hypothesis (Δ AICc) of candidate models explaining variation in bird guild density in **Hill forest** as a function of vegetation, disturbance and invasive cover during (a) breeding and (b) non-breeding season of 2009–11

Guild	**SUMMER**			**WINTER**		
	Model	AICc	Δ AICc	Model	AICc	Δ AICc
Canopy Insectivore	Fire +firewood collection	238.23	0	Lopping +fire	245.27	0
	Tree diversity +Tree crown cover	243.24	5.01	Tree crown cover +Tree diversity	250.89	5.61
	Tree basal area +CV of Tree crown cover	250.52	12.3	Lopping +CV of Tree crown cover	251.23	5.95
				Tree crown cover +CV of Tree crown cover	255.05	9.78
Understory-Insectivore	Fire+ Lantana density	196.92	0	Grazing +Lopping +shrub diversity	223.26	0
	Grazing + Fire+ Lopping	202.86	5.94	Grazing +Fire+ Lopping	226.93	3.67
	Shrub diversity+ lantana density+ Shrub volume	204.01	7.09	Shrub diversity+ Lantana density+ Shrub volume	226.93	3.68
	Cv of Tree crown cover+% canopy cover+ Tree basal area	215.42	18.5	CV of tree crown cover+% canopy cover+ Tree basal area	236.47	13.21
Sallying Insectivore	% canopy cover	206.59	0	Tree diversity	237.28	0
	% canopy cover+ Tree diversity+	210.27	3.68	Firewood collection+ fire	240.74	3.46

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Table F.1 – *Continued from previous page*

Guild	**SUMMER**			**WINTER**		
	Model	AICc	Δ AICc	Model	AICc	Δ AICc
	Firewood collection+ fire	218.22	11.63	Lantana density+ Shrub volume	243.72	6.44
	Lantana density+ Shrub volume	219.66	13.07	CV of tree crown cover+ Tree diversity	250.73	13.45
Trunk-bark feeder	Tree density+ Lopping	385.74	0	Lopping+ Tree density	177.61	0
	Tree basal area+ Tree density	388.24	2.5	Tree basal area+ CV of tree crown cover	185.77	8.16
	Lopping+ firewood collection+ fire	389.96	4.22	Lopping+ Timber extraction+ fire+ firewood collection	187.27	9.67
	CV of tree crown cover+ tree density +Tree diversity	392.3	6.56			
Frugivore	% canopy cover+ Shrub diversity	192.1	0	Tree diversity+ Tree crown cover	80.1	0
	% canopy cover+ Tree diversity	196.18	4.08	Lopping+ Fire	83.23	3.13
	Fire+ Lopping	196.71	4.61	Lantana density+% canopy cover	84.95	4.85
	CV of tree crown cover +Tree density	201.92	9.82			
Fruit Seed Nectar Insectivore	Shrub diversity + Lantana density	236.46	0	Shrub diversity+ Tree diversity	200.66	0

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Table F.1 – *Continued from previous page*

Guild	**SUMMER**			**WINTER**		
	Model	AICc	Δ AICc	Model	AICc	Δ AICc
	Lopping + Fire	242.16	5.7	Lantana density+% canopy cover	205.4	4.75
	Tree diversity+% canopy cover	242.79	6.33	Lopping+ firewood collection+ fire	208.79	8.13
Omnivore	Grazing+ Lantana cover	186.75	0	Fire+ Lantana density	100.34	0
	Timber extraction+ Grazing	189.16	2.41	Lopping+ fire	104.07	3.73
	% canopy cover+ Lantana density	191.39	4.64	Tree density+ Tree diversity	106.38	6.04
	% canopy cover+ Lantana density	192.4	5.65	Tree density+% canopy cover	107.49	7.16
Granivore	Grazing+ firewood collection	234.82	0			
	% canopy cover+ Lantana cover+ fire	240.52	5.7			
	Lopping+ grazing+ firewood collection+ fire	242.39	7.57			
Nectar-Insectivore	Firewood collection+ Lantana density	184.44	0	Fire +lantana density	262.15	0
	Firewood collection + Fire	194.33	9.89	Fire+ lopping	265.91	3.76
	Tree diversity+ shrub diversity	199.31	14.87	Shrub volume+ Lantana density	268.24	6.09

APPENDIX G

Summary statistics [Akaike Information Criteria (AICc) and relative support for hypothesis (Δ AICc) of candidate models explaining variation in bird guild density in **Moist forest** as a function of vegetation, disturbance and invasive cover during (a) breeding and (b) non-breeding season of 2009–11

Guild	**SUMMER**			**WINTER**		
	Model	AICc	Δ AICc	Model	AICc	Δ AICc
Canopy Insectivore	Tree diversity	304.01	0	Fire	214.38	0
	Tree diversity +tree basal area	307.21	3.19	Tree diversity	216.85	2.47
	Average tree basal area+ tree density	328.05	24.03	Tree basal area+ Tree diversity	221.27	6.88
	Lopping+ Timber extraction	331.21	27.19	Tree basal area+ Tree density	222.43	8.04
				Lopping +fire+ Timber extraction	222.52	8.13
Understory-Insectivore	Lopping+ lantana density+ Grazing	572.44	0	Tree basal area+ Lantana cover	258.12	0
	Lopping+ firewood collection+ Grazing	575.83	3.39	Lantana cover+ grazing	261.28	3.15
	Lantana density+% Canopy cover	580.37	7.93	Shrub volume+ Lantana cover	261.49	3.37
	Shrub volume+ lantana density	583.78	11.34	Lopping+ firewood collection+ fire+ grazing	268.8	10.71
Sallying Insectivore	%canopy cover +fire+ Tree crown cover +fire	435.62	0	Shrub volume+ grazing+ Fire	158.87	0

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Table G.1 – *Continued from previous page*

Guild	**SUMMER**			**WINTER**		
	Model description	AICc	Δ AICc	Model description	AICc	Δ AICc
	% canopy cover + Tree diversity	439.15	3.53	Fire+ timber extraction	165.8	6.93
	Tree den +lantana density	450.06	14.44	% canopy cover+ Tree crown cover	166.93	8.07
	%canopy cover+ fire+ Tree crown cover	453.77	18.15	% canopy cover+ tree density	167.91	9.04
Trunk-bark feeder	Tree diversity+ tree basal area	163.42	0	Tree density+% canopy cover	159.12	0
	Lopping+ Firewood collection	166.98	3.57	Tree basal area+% canopy cover	162.8	3.68
	Tree density+ Tree diversity	167.14	3.72	Timber extraction +fire +firewood collection	171.13	12.01
	Average tree basal area+% canopy cover	168.61	5.19			
Frugivore	Timber extraction+ lantana density	43.87	0	Timber extraction+ Tree density	69.021	0
	Tree diversity+ lantana density	45.89	2.01	Tree diversity+ lantana density	73.949	4.92
	Timber extraction+ lopping+ firewood collection	57.62	13.74	Lopping+ Timber extraction	75.32	6.29
				Tree basal area+ lantana density	77.63	8.6

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Table G.1 – *Continued from previous page*

Guild	**SUMMER**			**WINTER**		
	Model description	AICc	Δ AICc	Model description	AICc	Δ AICc
Fruit Seed Nectar Insectivore	Lantana cover+% canopy cover	201.88	0	Lantana cover	197.97	0
	% canopy cover+ firewood collection+ Lantana cover	205.42	3.54	Lantana cover+ Tree density	201.19	3.22
	Tree diversity +Tree crown cover	209.55	7.67	Tree crown cover+ Tree diversity+ Shrub diversity	206.22	8.24
	Firewood collection+ timber extraction	211.18	9.3	Lopping+ firewood collection+ Timber extraction	212.72	14.75
Omnivore	% canopy cover+ lantana cover+ Lopping	218.09	0	Fire	119.35	0
	% canopy cover +Tree diversity	220.54	2.45	Fire+ Tree density	124.48	5.12
	Lopping+ Lantana cover+ Tree density	231.72	13.63	Timber extraction+ fire	125.14	5.78
				Lantana density+% canopy cover	129.09	9.74
Granivore	% canopy cover	181.27	0			
	% canopy cover+ Lantana density	184.91	3.64			
	Lopping+ Firewood collection	189.98	8.71			

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Table G.1 – *Continued from previous page*

Guild	**SUMMER**			**WINTER**		
	Model description	AICc	Δ AICc	Model description	AICc	Δ AICc
	% canopy cover+ Lantana density+ shrub cover+ fire	193.53	12.26			
Nectar-Insectivore	Tree diversity +Shrub diversity	257.44	0	Lantana cover	247.73	0
	Lopping+ fire	260.07	2.63	Lantana cover +shrub cover	250.25	2.52
	Lantana density +Shrub volume	260.47	3.03	Lantana cover+ Timber extraction	251.81	4.08
				Tree diversity +Shrub diversity	258.2	10.47
				Timber extraction +fire	259.82	12.09

APPENDIX H

Table H.1.: Co-ordinates of all intensive sampling point across forest type. RNP=Rajaji National Park, DFD=Dehradun Forest Division, SFD=Shiwalik Forest Division.

S.No.	Forest type	Plot-ID	Point-ID	Latitude	Longitude	Location
1	DRY	ANDHERI	TA1	30.1127	77.9475	RNP
2	DRY	ANDHERI	TA2	30.1106	77.9458	RNP
3	DRY	ANDHERI	TA3	30.1088	77.9436	RNP
4	DRY	ANDHERI	TB1	30.1104	77.9489	RNP
5	DRY	ANDHERI	TB2	30.1085	77.9472	RNP
6	DRY	ANDHERI	TB3	30.1070	77.9451	RNP
7	DRY	ANDHERI	TC1	30.1086	77.9509	RNP
8	DRY	ANDHERI	TC2	30.1064	77.9493	RNP
9	DRY	ANDHERI	TC3	30.1044	77.9475	RNP
10	DRY	BAM	TA1	30.0606	77.9949	RNP
11	DRY	BAM	TA2	30.0599	77.9976	RNP
12	DRY	BAM	TA3	30.0593	77.9997	RNP
13	DRY	BAM	TB1	30.0547	78.0000	RNP
14	DRY	BAM	TB2	30.0555	78.0018	RNP
15	DRY	BAM	TB3	30.0574	78.0011	RNP
16	DRY	BAM	TC1	30.0561	77.9979	RNP
17	DRY	BAM	TC2	30.0582	77.9965	RNP
18	DRY	BEENJ	TA1	30.1064	77.9616	RNP
19	DRY	BEENJ	TA2	30.1046	77.9609	RNP
20	DRY	BEENJ	TA3	30.1025	77.9599	RNP
21	DRY	BEENJ	TB1	30.1074	77.9589	RNP
22	DRY	BEENJ	TB2	30.1057	77.9579	RNP
23	DRY	BEENJ	TB3	30.1037	77.9571	RNP
24	DRY	BEENJ	TC1	30.1095	77.9573	RNP
25	DRY	BEENJ	TC2	30.1080	77.9564	RNP
26	DRY	BEENJ	TC3	30.1061	77.9554	RNP
27	DRY	CHILAWALI	TA1	30.1442	77.9392	RNP

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Table H.1 – *Continued from previous page*

S.No.	**Forest type**	**Plot-ID**	**Point-ID**	**Latitude**	**Longitude**	**Location**
28	DRY	CHILAWALI	TA2	30.1414	77.9379	RNP
29	DRY	CHILAWALI	TA3	30.1388	77.9366	RNP
30	DRY	CHILAWALI	TB1	30.1428	77.9363	RNP
31	DRY	CHILAWALI	TB2	30.1402	77.9410	RNP
32	DRY	CHILAWALI	TB3	30.1376	77.9399	RNP
33	DRY	CHILAWALI	TC1	30.1449	77.9445	RNP
34	DRY	CHILAWALI	TC2	30.1463	77.9427	RNP
35	DRY	CHILAWALI	TC3	30.1468	77.9406	RNP
36	DRY	DHOLKHAND1	TA1	30.1051	77.9719	RNP
37	DRY	DHOLKHAND1	TA2	30.1059	77.9743	RNP
38	DRY	DHOLKHAND1	TA3	30.1066	77.9765	RNP
39	DRY	DHOLKHAND1	TB1	30.1080	77.9691	RNP
40	DRY	DHOLKHAND1	TB2	30.1086	77.9721	RNP
41	DRY	DHOLKHAND1	TB3	30.1093	77.9750	RNP
42	DRY	DHOLKHAND1	TC1	30.1105	77.9675	RNP
43	DRY	DHOLKHAND1	TC2	30.1121	77.9696	RNP
44	DRY	DHOLKHAND1	TC3	30.1130	77.9762	RNP
45	DRY	GANJARBAN	TA1	30.0723	77.9388	RNP
46	DRY	GANJARBAN	TA2	30.0731	77.9409	RNP
47	DRY	GANJARBAN	TA3	30.0741	77.9431	RNP
48	DRY	GANJARBAN	TB3	30.0760	77.9421	RNP
49	DRY	GANJARBAN	TC1	30.0724	77.9365	RNP
50	DRY	GANJARBAN	TC2	30.0734	77.9348	RNP
51	DRY	GANJARBAN	TC3	30.0752	77.9329	RNP
52	DRY	KANIYA	TA1	30.0672	77.9826	RNP
53	DRY	KANIYA	TA2	30.0653	77.9818	RNP
54	DRY	KANIYA	TA3	30.0639	77.9812	RNP
55	DRY	KANIYA	TB1	30.0686	77.9793	RNP
56	DRY	KANIYA	TB2	30.0668	77.9787	RNP
57	DRY	KANIYA	TB3	30.0646	77.9783	RNP
58	DRY	KANIYA	TC1	30.0693	77.9763	RNP
59	DRY	KANIYA	TC2	30.0778	77.9758	RNP
60	DRY	KANIYA	TC3	30.0659	77.9749	RNP
61	DRY	LAKARKOT	TA1	30.0827	77.9351	RNP
62	DRY	LAKARKOT	TA2	30.0847	77.9378	RNP
63	DRY	LAKARKOT	TA3	30.0865	77.9400	RNP
64	DRY	LAKARKOT	TB1	30.0808	77.9413	RNP
65	DRY	LAKARKOT	TB2	30.0831	77.9425	RNP
66	DRY	LAKARKOT	TB3	30.0852	77.9432	RNP
67	DRY	LAKARKOT	TC1	30.0101	77.9376	RNP
68	DRY	LAKARKOT	TC2	30.0776	77.9400	RNP
69	DRY	LAKARKOT	TC3	30.0786	77.9439	RNP
70	DRY	SHIKARIBADA	TA1	30.1006	77.9689	RNP
71	DRY	SHIKARIBADA	TA2	30.1003	77.9692	RNP

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Table H.1 – *Continued from previous page*

S.No.	**Forest type**	**Plot-ID**	**Point-ID**	**Latitude**	**Longitude**	**Location**
72	DRY	SHIKARIBADA	TA3	30.1003	77.9672	RNP
73	DRY	SHIKARIBADA	TB1	30.1031	77.9688	RNP
74	DRY	SHIKARIBADA	TB2	30.1026	77.9678	RNP
75	DRY	SHIKARIBADA	TB3	30.1025	77.9694	RNP
76	DRY	SHIKARIBADA	TC1	30.1048	77.9684	RNP
77	DRY	SHIKARIBADA	TC2	30.1045	77.9694	RNP
78	DRY	SHIKARIBADA	TC3	30.1038	77.9669	RNP
79	DRY	SUKH	TA1	30.1677	77.9082	RNP
80	DRY	SUKH	TA2	30.1661	77.9081	RNP
81	DRY	SUKH	TA3	30.1634	77.9075	RNP
82	DRY	SUKH	TB1	30.1609	77.9165	RNP
83	DRY	SUKH	TB2	30.1618	77.9132	RNP
84	DRY	SUKH	TB3	30.1626	77.9103	RNP
85	DRY	SUKH	TC1	30.1662	77.9147	RNP
86	DRY	SUKH	TC2	30.1670	77.9116	RNP
87	DRY	SUKH	TC3	30.1681	77.9089	RNP
88	HILL	ANDHERI B	TA1	30.1271	77.9554	RNP
89	HILL	ANDHERI B	TA2	30.1284	77.9576	RNP
90	HILL	ANDHERI B	TA3	30.1284	77.9598	RNP
91	HILL	ANDHERI B	TB1	30.1273	77.9621	RNP
92	HILL	ANDHERI B	TB2	30.1261	77.9664	RNP
93	HILL	ANDHERI B	TB3	30.1241	77.9652	RNP
94	HILL	ANDHERI B	TC1	30.1242	77.9626	RNP
95	HILL	ANDHERI B	TC2	30.1233	77.9598	RNP
96	HILL	ANDHERI B	TC3	30.1229	77.9576	RNP
97	HILL	ANDHERI NEW	TA1	30.1420	77.9607	RNP
98	HILL	ANDHERI NEW	TA2	30.1438	77.9601	RNP
99	HILL	ANDHERI NEW	TA3	30.1438	77.9622	RNP
100	HILL	ANDHERI NEW	TB1	30.1436	77.9647	RNP
101	HILL	ANDHERI NEW	TB2	30.1438	77.9673	RNP
102	HILL	ANDHERI NEW	TB3	30.1420	77.9671	RNP
103	HILL	ANDHERI NEW	TC1	30.1403	77.9666	RNP
104	HILL	ANDHERI NEW	TC2	30.1399	77.9633	RNP
105	HILL	ANDHERI NEW	TC3	30.1380	77.9642	RNP
106	HILL	ANICUT	TA1	30.1087	77.9888	RNP
107	HILL	ANICUT	TA2	30.1086	77.9873	RNP
108	HILL	ANICUT	TA3	30.1098	77.9866	RNP
109	HILL	ANICUT	TB1	30.1111	77.9866	RNP
110	HILL	ANICUT	TB2	30.1109	77.9875	RNP
111	HILL	ANICUT	TB3	30.1106	77.9883	RNP
112	HILL	ANICUT	TC1	30.1108	77.9894	RNP
113	HILL	ANICUT	TC2	30.1112	77.9908	RNP
114	HILL	ANICUT	TC3	30.1129	77.9912	RNP
115	HILL	BAMB	TA1	30.0680	77.9973	RNP

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Table H.1 – *Continued from previous page*

S.No.	Forest type	Plot-ID	Point-ID	Latitude	Longitude	Location
116	HILL	BAMB	TA2	30.0701	77.9985	RNP
117	HILL	BAMB	TA3	30.0717	78.0001	RNP
118	HILL	BAMB	TB1	30.0739	78.9999	RNP
119	HILL	BAMB	TB2	30.0754	78.9981	RNP
120	HILL	BAMB	TB3	30.0753	78.9955	RNP
121	HILL	BAMB	TC1	30.0739	78.9942	RNP
122	HILL	BAMB	TC2	30.0715	78.9944	RNP
123	HILL	BAMB	TC3	30.0698	78.9965	RNP
124	HILL	CHILAWALIB	TA1	30.1716	77.9407	RNP
125	HILL	CHILAWALIB	TA2	30.1726	77.9399	RNP
126	HILL	CHILAWALIB	TA3	30.1727	77.9389	RNP
127	HILL	CHILAWALIB	TB1	30.1745	77.9402	RNP
128	HILL	CHILAWALIB	TB2	30.1759	77.9401	RNP
129	HILL	CHILAWALIB	TB3	30.1776	77.9416	RNP
130	HILL	CHILAWALIB	TC1	30.1752	77.9461	RNP
131	HILL	CHILAWALIB	TC2	30.1764	77.9437	RNP
132	HILL	CHILAWALIB	TC3	30.1772	77.9426	RNP
133	HILL	DHOLKHAND 1B	TA1	30.1142	77.9649	RNP
134	HILL	DHOLKHAND 1B	TA2	30.1158	77.9660	RNP
135	HILL	DHOLKHAND 1B	TA3	30.1175	77.9669	RNP
136	HILL	DHOLKHAND 1B	TB1	30.1173	77.9692	RNP
137	HILL	DHOLKHAND 1B	TB2	30.1152	77.9695	RNP
138	HILL	DHOLKHAND 1B	TB3	30.1142	77.9687	RNP
139	HILL	DHOLKHAND 1B	TC1	30.1123	77.9503	RNP
140	HILL	DHOLKHAND 1B	TC2	30.1147	77.9509	RNP
141	HILL	DHOLKHAND 1B	TC3	30.1169	77.9526	RNP
142	HILL	SUKHB	TA1	30.1657	77.9174	RNP
143	HILL	SUKHB	TA2	30.1672	77.9173	RNP
144	HILL	SUKHB	TA3	30.1689	77.9173	RNP
145	HILL	SUKHB	TB1	30.1709	77.9168	RNP
146	HILL	SUKHB	TB2	30.1716	77.9149	RNP
147	HILL	SUKHB	TB3	30.1709	77.9168	RNP
148	HILL	SUKHB	TC1	30.1762	77.9142	RNP
149	HILL	SUKHB	TC2	30.1753	77.9137	RNP
150	HILL	SUKHB	TC3	30.1742	77.9134	RNP
151	HILL	TIGERNALA	TA1	30.1000	77.9921	RNP
152	HILL	TIGERNALA	TA2	30.1011	77.9931	RNP
153	HILL	TIGERNALA	TA3	30.1025	77.9939	RNP
154	HILL	TIGERNALA	TB1	30.1015	77.9954	RNP
155	HILL	TIGERNALA	TB2	30.1025	77.9966	RNP
156	HILL	TIGERNALA	TB3	30.1027	77.9950	RNP
157	HILL	TIGERNALA	TC1	30.0997	77.9951	RNP
158	HILL	TIGERNALA	TC2	30.0992	77.9955	RNP
159	HILL	TIGERNALA	TC3	30.0989	77.9976	RNP

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Table H.1 – *Continued from previous page*

S.No.	**Forest type**	**Plot-ID**	**Point-ID**	**Latitude**	**Longitude**	**Location**
160	MOIST	ASARORI	TA1	30.2498	77.9735	DFD
161	MOIST	ASARORI	TA2	30.2517	77.9748	DFD
162	MOIST	ASARORI	TA3	30.2529	77.9736	DFD
163	MOIST	ASARORI	TB1	30.2540	77.9691	DFD
164	MOIST	ASARORI	TB2	30.2544	77.9717	DFD
165	MOIST	ASARORI	TB3	30.2529	77.9736	DFD
166	MOIST	ASARORI	TC1	30.2517	77.9682	DFD
167	MOIST	ASARORI	TC2	30.2505	77.9704	DFD
168	MOIST	ASARORI	TC2	30.2505	77.9704	DFD
169	MOIST	ASARORI	TC3	30.2489	77.9713	DFD
170	MOIST	BULINDAWALA	TA1	30.1671	78.0631	DFD
171	MOIST	BULINDAWALA	TA2	30.1661	78.0613	DFD
172	MOIST	BULINDAWALA	TA3	30.1659	78.0600	DFD
173	MOIST	BULINDAWALA	TB1	30.1690	78.0603	DFD
174	MOIST	BULINDAWALA	TB2	30.1680	78.0603	DFD
175	MOIST	BULINDAWALA	TB3	30.1673	78.0594	DFD
176	MOIST	BULINDAWALA	TC1	30.1698	78.0615	DFD
177	MOIST	BULINDAWALA	TC2	30.1709	78.0614	DFD
178	MOIST	BULINDAWALA	TC2	30.1709	78.0614	DFD
179	MOIST	BULINDAWALA	TC3	30.1718	78.0625	DFD
180	MOIST	DHARMAWALA	TA1	30.3670	77.7438	DFD
181	MOIST	DHARMAWALA	TA2	30.3651	77.7457	DFD
182	MOIST	DHARMAWALA	TA2	30.3651	77.7457	DFD
183	MOIST	DHARMAWALA	TA3	30.3616	77.7455	DFD
184	MOIST	DHARMAWALA	TB1	30.3648	77.7479	DFD
185	MOIST	DHARMAWALA	TB2	30.3622	77.7479	DFD
186	MOIST	DHARMAWALA	TB3	30.3582	77.7473	DFD
187	MOIST	DHARMAWALA	TC1	30.3635	77.7510	DFD
188	MOIST	DHARMAWALA	TC2	30.3604	77.7508	DFD
189	MOIST	DHARMAWALA	TC3	30.3573	77.7508	DFD
190	MOIST	KALUWALA	TA1	30.3136	77.8668	DFD
191	MOIST	KALUWALA	TA2	30.3110	77.8653	DFD
192	MOIST	KALUWALA	TA3	30.3085	77.8645	DFD
193	MOIST	KALUWALA	TB1	30.3123	77.8685	DFD
194	MOIST	KALUWALA	TB2	30.3094	77.8674	DFD
195	MOIST	KALUWALA	TB3	30.3073	77.8664	DFD
196	MOIST	KALUWALA	TC1	30.3115	77.8716	DFD
197	MOIST	KALUWALA	TC2	30.3089	77.8708	DFD
198	MOIST	KALUWALA	TC3	30.3060	77.8691	DFD
199	MOIST	KARWAPANI 5	TA1	30.2698	77.9321	DFD
200	MOIST	KARWAPANI 5	TA2	30.2718	77.9300	DFD
201	MOIST	KARWAPANI 5	TA3	30.2704	77.9265	DFD
202	MOIST	KARWAPANI 5	TB1	30.2667	77.9324	DFD
203	MOIST	KARWAPANI 5	TB2	30.2668	77.9293	DFD

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Table H.1 – *Continued from previous page*

S.No.	Forest type	Plot-ID	Point-ID	Latitude	Longitude	Location
204	MOIST	KARWAPANI 5	TB3	30.2684	77.9281	DFD
205	MOIST	KARWAPANI 5	TC1	30.2668	77.9349	DFD
206	MOIST	KARWAPANI 5	TC2	30.2644	77.9348	DFD
207	MOIST	KARWAPANI 5	TC3	30.2628	77.9323	DFD
208	MOIST	LALDHANG 5	TA1	30.2761	77.9597	DFD
209	MOIST	LALDHANG 5	TA2	30.2738	77.9596	DFD
210	MOIST	LALDHANG 5	TA3	30.2716	77.9597	DFD
211	MOIST	LALDHANG 5	TB1	30.2748	77.9547	DFD
212	MOIST	LALDHANG 5	TB2	30.2728	77.9560	DFD
213	MOIST	LALDHANG 5	TB3	30.2709	77.9571	DFD
214	MOIST	LALDHANG 5	TC1	30.2752	77.9526	DFD
215	MOIST	LALDHANG 5	TC2	30.2731	77.9533	DFD
216	MOIST	LALDHANG 5	TC3	30.2717	77.9545	DFD
217	MOIST	MALHAN	TA1	30.3008	77.8854	DFD
218	MOIST	MALHAN	TA2	30.2986	77.8843	DFD
219	MOIST	MALHAN	TA3	30.2959	77.8991	DFD
220	MOIST	MALHAN	TB1	30.2980	77.8882	DFD
221	MOIST	MALHAN	TB2	30.2956	77.8866	DFD
222	MOIST	MALHAN	TB3	30.2930	77.8849	DFD
223	MOIST	MALHAN	TC1	30.2965	77.8898	DFD
224	MOIST	MALHAN	TC2	30.2947	77.8887	DFD
225	MOIST	MALHAN	TC3	30.2922	77.8873	DFD
226	MOIST	SABBAWALA	TA1	30.3648	77.7829	DFD
227	MOIST	SABBAWALA	TA2	30.3630	77.7828	DFD
228	MOIST	SABBAWALA	TA3	30.3600	77.7828	DFD
229	MOIST	SABBAWALA	TB1	30.3631	77.7785	DFD
230	MOIST	SABBAWALA	TB2	30.3605	77.7794	DFD
231	MOIST	SABBAWALA	TB3	30.3583	77.7807	DFD
232	MOIST	SABBAWALA	TC1	30.3622	77.7758	DFD
233	MOIST	SABBAWALA	TC2	30.3596	77.7768	DFD
234	MOIST	SABBAWALA	TC3	30.3576	77.7780	DFD
235	MOIST	TIMLI	TA1	30.3700	77.7688	DFD
236	MOIST	TIMLI	TA2	30.3688	77.7663	DFD
237	MOIST	TIMLI	TA3	30.3676	77.7640	DFD
238	MOIST	TIMLI	TB1	30.3678	77.7714	DFD
239	MOIST	TIMLI	TB2	30.3661	77.7688	DFD
240	MOIST	TIMLI	TB3	30.3645	77.7660	DFD
241	MOIST	TIMLI	TC1	30.3652	77.7720	DFD
242	MOIST	TIMLI	TC2	30.3640	77.7696	DFD
243	MOIST	TIMLI	TC3	30.3628	77.7668	DFD
244	HILL	KHAJNAWAR	TA1	30.1940	77.8852	SFD
245	HILL	KHAJNAWAR	TA2	30.1959	77.8859	SFD
246	HILL	KHAJNAWAR	TA3	30.1961	77.8876	SFD
247	HILL	KHAJNAWAR	TB1	30.1971	77.8846	SFD

Continued on next page

Table H.1 – *Continued from previous page*

S.No.	**Forest type**	**Plot-ID**	**Point-ID**	**Latitude**	**Longitude**	**Location**
248	HILL	KHAJNAWAR	TB2	30.1967	77.8861	SFD
249	HILL	KHAJNAWAR	TB3	30.1969	77.8872	SFD
250	HILL	KHAJNAWAR	TC1	30.1966	77.8841	SFD
251	HILL	KHAJNAWAR	TC2	30.1950	77.8838	SFD
252	HILL	KHAJNAWAR	TC3	30.1938	77.8836	SFD
253	HILL	KHARASOT	TA1	30.1861	77.8934	SFD
254	HILL	KHARASOT	TA2	30.1874	77.8923	SFD
255	HILL	KHARASOT	TA3	30.1885	77.8913	SFD
256	HILL	KHARASOT	TB1	30.1895	77.8909	SFD
257	HILL	KHARASOT	TB2	30.1912	77.8908	SFD
258	HILL	KHARASOT	TB3	30.1907	77.8916	SFD
259	HILL	KHARASOT	TC1	30.1901	77.8943	SFD
260	HILL	KHARASOT	TC2	30.1893	77.8939	SFD
261	HILL	KHARASOT	TC3	30.1882	77.8947	SFD

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RESPONSE OF MIGRANT AND RESIDENT BIRD COMMUNITIES TO ANTHROPOGENIC DISTURBANCES IN SHIWALIK LANDSCAPE, UTTARAKHAND, INDIA

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Frequent compounded perturbations in terms of lopping, grazing, biological invasions, firewood and non-timber forest product (NTFP) collection gradually alters the habitat, and consequently dependent biotic communities. However, it is quite difficult to quantify these disturbances due to their high frequency, low intensity, and interaction among themselves. In order to quantify and investigate the impact of such disturbances on the habitat of resident and migrant birds, we carried out a study in the dry forest of Rajaji National Park in the Shiwalik landscape. Grazing and firewood collection emerged as the major disturbance in the study area, which decreased linearly from the edge to the interior of the forest. Disturbance altered the structural components of the vegetation; however, we did not find major changes in the vegetation composition. Canopy opening due to lopping disturbance facilitated the growth of *Lantana camara* in the study area. Ninety percent of the migrant bird community wintering in the study area belonged to the insectivorous guild. Out of 18 migrant species observed during the entire study period, 44% belonged to understorey-insectivores guild and 33% to canopy-insectivores. However, in terms of abundance 67% of the migrants pertained to the canopy-insectivores guild. Guild composition in resident birds was more varied with a total of 11 guilds, and trunk-bark feeder guild comprised the maximum number of species (20%). Species richness of both migrant and resident birds did not change much with any of the disturbance components. However, densities of resident birds increased with increased lopping and timber extraction in the study area during winter. Resident and migrant birds exhibited similar distribution patterns across different disturbance gradients indicating equivalent sensitivity to disturbances.

Key words: bird communities, Rajaji National Park, disturbances, heterospecific attraction

INTRODUCTION

Conservationists throughout the world are concerned about the declining number of migratory bird species (Calvert *et al.* 2009; Faaborg *et al*. 2010; Terborgh 1989; Wilcove and Wikelski 2008). It becomes difficult to determine the actual cause of migratory bird decline due to the variety of habitat use during different phases of life cycle (Faaborg *et al*. 2010). Habitat conditions in breeding, stopover and wintering sites are the key factors influencing survival and reproduction of migrants (Sherry and Holmes 1995). Research and management of migrant birds generally focuses on conditions in the breeding sites where they spend less time than their wintering sites. Protection and food resources in wintering areas ensure survival of individuals as well as nutrient build up for migrating back to the breeding grounds and possibly for future reproduction (Calvert *et al*. 2009). Some of the migratory birds spend more time in their wintering and stopover sites than their breeding sites. Therefore, habitat degradation in wintering sites could have detrimental effect for migratory birds (Terborgh 1989). During their stay in wintering sites, migrants interact and share resources with resident bird species. Due to their high abundance in secondary forest and degraded areas, migrants are assumed to be subordinate to resident bird species (Powell 1980; Rappole *et al*. 1983). However, Terborgh (1989) emphasised that migrants are not weedy opportunists in tropical forests, but an integral part of the overall bird community.

Rapid degradation of wintering areas of these species puts direct pressure on the survival and future reproduction of migrants. Subsistence use of forest by the communities residing in and around protected areas (PAs) is one of the major causes of the degradation of forests throughout the world. The situation is more alarming in developing countries like India where approximately 69% of the PAs are inhabited by local communities whose population was put at *c*. 4.5 million (Kothari *et al.* 1989). These communities depend on forest not only for their survival, but also for livelihood. Removal of vegetation biomass during these disturbances modifies the habitat structure and composition (Daniels *et al*. 1995; Kumar and Shahabuddin 2005; Murali *et al*. 1996; Sagar *et al*. 2003), which in turn has implications for the survival and reproductive fitness of the biotic communities (Shahabuddin and Kumar 2006). Information about distribution of migrants in different quality wintering habitats, in relation to resident species, is still lacking from tropical countries, including India.

In this study we first investigated the impact of extractive disturbances on vegetation structure and composition in the dry plain Sal forest of Rajaji National Park

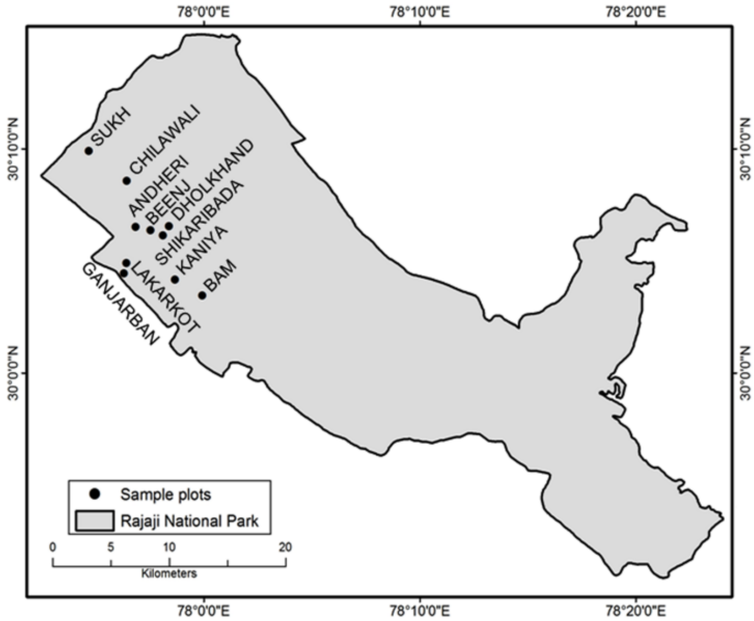

Fig. 1: Rajaji National Park, showing location of the sampling plots

and then examined the patterns of distribution of non-breeding winter migrants and resident bird species across different disturbance gradients. Finally we explored the relationship between resident and migrants across all the sampling plots to test how one community distributes itself in relation to others.

STUDY AREA

The study was conducted in Rajaji National Park (29°52' –30°15' N; 77°55'–78°5' E), one of the most important protected areas of India for the conservation of two charismatic mammal species, i.e. Tiger *Panthera tigris* and Asian Elephant *Elephas maximus*. Located in the north-western region of Shiwalik Hills of Uttarakhand state, Rajaji National Park (hereafter RNP) covers an area of 820 sq. km.

Intensive study sites were located in the dry plain Sal forest (5B/CI B) in the southern side of RNP (Champion and Seth 1968). This region is characterised by its serrated topography, with a number of steep ridges which emerge from the main Shiwalik ridge and have narrow valleys between them. Sal *Shorea robusta* forms the climax species of the forest succession and is the dominant species of this forest type. Most typical associates of Sal in this forest are *Terminalia tomentosa*, *Terminalia bellerica* and *Lagerstroemia parviflora* in the middle canopy. The understorey constitutes *Mallotus philippensis*, *Ehretia laevis*, *Cassia fistula*, *Miliusa velutina*, and *Holarrhena antidysenterica*. *Clerodendrum viscosum*, *Murraya koenigii*, *Colebrookea oppositifolia*, and *Adhatoda vasica* form the shrub layer. *Lantana camara* (hereafter lantana), an exotic invasive, occupies a large area in this forest type and forms dense thickets in disturbed areas.

This area has been home to a nomadic pastoral community – the Gujjars – for at least the last eight decades (Kumar 1995). Gujjars rely heavily on the forest for lopped fodder resources for their livestock to support their dairy product based economy, and for fuel and timber requirements. Till 2003, as much as 86% of the RNP was open to the Gujjar community for lopping and grazing. Indiscriminate lopping year after year resulted in tree mortality and weed infestation. In the past, Gujjars used to leave their dwellings in the landscape with the advent of summer around April for high altitude meadows in the Himalaya, where they would stay until October. However, now partly due to the fact that local communities in the Himalaya do not want to share their resources with the Gujjars and partly owing to socio-economic changes within the community itself, most of them have abandoned this traditional migration. The reduction in migration has resulted in their increased demands on the RNP landscape. However, a major relocation drive, started almost a decade back, of the Gujjar families from RNP to Haridwar

(Pathri and Gaindikahta resettlement colonies) helped in considerable release of pressure on the forest. As a result, some ranges have little to moderate disturbance by Gujjars, whereas others are completely undisturbed. Another major disturbance in this area is the collection of non-timber forest products (NTFP), including Bhabar grass *Eulaliopsis binata* (Dhaundiyal 1997). Bhabar grass contributes significantly to the subsistence economy of the large number of people living on the boundary of the dry plain forest. However, due to restrictions imposed under the Wildlife (Protection) Act, Bhabar grass collection was banned inside the Park. Therefore, the relocation of Gujjars, and stringent implementation of the law by forest officials, has created a gradient of disturbances in the study area.

The bird diversity of this region is even more remarkable, with 312 species of birds (Pandey *et al*. 1994). Of these, 144 are residents, 89 are migrants, 53 are altitudinal migrants, and the status of 18 is unknown.

METHODS

1. Site selection

To find out the relationship between disturbance, vegetation and bird communities sampling plots were chosen across a gradient of human disturbance through a preliminary survey in dry plain Sal forest (Fig. 1) of RNP. A total of 10 sampling sites were chosen across the entire landscape. At each site a 1 x 1 km representative area, which was reasonably homogenous, was delineated (grid) as sampling plot, leaving a buffer of at least 250 m from the boundary to negate 'edge effects'. Each plot again had three parallel line-transects at a distance of 250 m from the edge of the grid. On each transect three points were marked at a distance of 250 m (Fig. 2). At each point, nested circular plots were established for enumerating vegetation structure and composition, and anthropogenic disturbances. The same points were used to collect data on bird composition and abundance through the variable radius point transect method. A total of 89 points were used for data collection on vegetation disturbance and birds.

2. Vegetation Sampling

Around each intensive sampling point concentric 10 m and 5 m radius plots were laid to enumerate vegetation structure and compositional attributes for the tree and shrub layer respectively. In total, 89 vegetation plots (one plot had 8 intensive sampling points) were laid for both tree and shrub layer variables during two winter seasons (2010-2011). All woody vegetation GBH 20 cm or above was considered as trees. In each 10 m radius plot number, identity of species, GBH, canopy spread in two perpendicular diameters, and top and bottom height of canopy for each tree was recorded. Percent canopy cover was measured directly by means of a spherical densitometer, as the average of crown-cover readings taken from the centre of the plot in four cardinal directions.

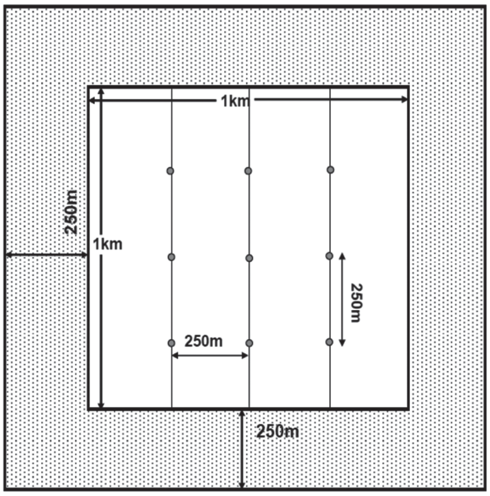

Fig. 2: Diagrammatic representation of the sampling plot. Each plot had an area of 1 sq. km with a buffer of 250 m on each side. Intensive sampling points were laid at a distance of 250 m from the edge of the plot (shown as points)

Shrub variables were measured in circular plots of 5 m radius nested in the tree plots mentioned above. All woody vegetation less than 20 cm GBH was considered as shrubs. In each shrub plot, species identity, number of individuals, height and canopy spread in two perpendicular diameters for each shrub was recorded.

3. Disturbance quantification

All the disturbance variables were quantified in the 20 m radius plot nested around the intensive sampling plot. Parameters used for quantification of disturbance were percentage of lopped trees (PERLOPP), lopping intensity on each tree (AVSCLOPP), number of dung pats (CATTDUNG), number of human trails passing through the plot (TRLN), percentage of grazing (GRZ), and number of cut trees (CUTTR) and cut stumps (CUTST). Intensity of lopping on each tree was estimated as an index. According to this index an intact tree with no sign of lopping gets zero value, a tree with less than half its branches lopped gets value 1, a tree with 50% lopped branches gets value 2, more than half of the branches lopped gets 3 and a tree with all branches lopped gets 4 (Shahabuddin and Kumar 2006).

4. Avifaunal sampling

Variable radius point transect method (Bibby 2000) was used to collect data on bird communities. All the points were at least 250 m apart from the centre of all the other points in the plot to avoid overlaps in bird encounters (Hansen *et al*. 1995). Birds were observed for 5 minutes at each point after an interval of 2 minutes from reaching the point (settling down time). It was observed that there were no substantial additional observations beyond the 5-minute period. Moreover, the chances of double counting get enhanced for longer periods. All birds seen or heard were recorded.

Additionally, the number of individuals and distance from the observer were also recorded. Distance was recorded using a laser rangefinder. All the birds were identified using standard field guides (Grimmett *et al*. 1999). All the point transects were conducted by a single observer (M. Kaushik) to avoid observer bias. Only the birds using the area during the count were recorded and all the birds that were transient were ignored.

Bird observations were made between 0.5 and 3 hrs after sunrise when visibility and bird activity is the highest (Raman *et al*. 1998). Only one plot comprising nine points was selected for bird sampling each day. All the points were visited for three mornings. To capture the maximum species variation during the study period, all the points were visited after a gap of at least seven days. Again, within a plot, the order of visiting the points was reversed each morning to negate the bias due to flushing of birds by the observer. Data of two winter seasons (2010-2011) was used for analysis.

STATISTICAL ANALYSIS

Principal component analysis (PCA) was carried out with the seven measured disturbance variables to extract the major disturbance regimes in the study area. All the disturbance variables were z-standardised (mean zero and unit standard deviation) before carrying out the PCA so that all variables got equal weight (Jongman *et al*. 1995; McGarigal *et al*. 2000). PCA was done using software SPSS (Version 16). Only those principal components with eigenvalue greater than one were selected. Pearson correlation was carried out between PCA scores of disturbance variables and vegetation variables (structural and compositional) to find out the relationship between them. Species richness and diversity were estimated for migrant and resident bird species through the point count data using software Pc-Ord version 4 (McCune and Mefford 1999). The density of resident and migrant birds was estimated using software Distance 5 (Thomas *et al*. 2010). Scatter plots in conjunction with generalised linear model (GLM) were used to investigate the response of both migrant and resident bird species to major disturbances in the study area. Distance of all the sampling plots was calculated using software ArcGIS. Correlation was done between different disturbance components and distance of sampling plots from the forest edge.

RESULTS

Disturbance variables were summarised using principal component analysis (PCA) and sampling plots were plotted on the first two disturbance components. Results of PCA extracted three major disturbance factors (i.e., grazing and fodder collection, lopping pressure and timber extraction), which explained 74% of the total variation in disturbance variables. Variation explained was 31%, 27%, and 16% by PC1, PC2, and PC3 respectively. Most of the variables positively contributed to the first principal component with the exception of variables related to timber extraction. The loadings for the second axis were low for the metrics related with livestock and firewood collection, but high for lopping disturbance (Table 1).

Segregation of sites using PCA corresponded closely with that made *a priori* by investigators. Of all the sampling plots, Lakarkot had the highest pressure due to grazing and firewood collection, followed by Andheri. Lopping pressure was highest in the Ganjarban and Sukh plots. Shikaribada showed lowest mean and variance for both disturbance gradients (Fig. 3).

Although all the disturbance components showed a declining trend with increased distance from the edge (grazing and fire wood collection: r = -0.40, p = 0.25; timber extraction: r = 0.47, p = 0.16), the trend was significant only for lopping pressure (r = -0.85, p = 0.001).

Table 1: Metric loadings for all three principal components extracted through Principal Component Analysis

	PC1	PC2	PC3
Grazing and Firewood collection			
TRLN	0.74	0.09	-0.04
CATTDUNG	0.64	0.05	0.47
CUTTR	0.76	-0.08	-0.12
GRZ	0.75	0.27	-0.01
Lopping pressure			
AVSCLOPP	0.07	0.95	0.03
PERLOPP	0.12	0.94	0.07
Timber extraction			
CUTST	-0.11	0.06	0.93

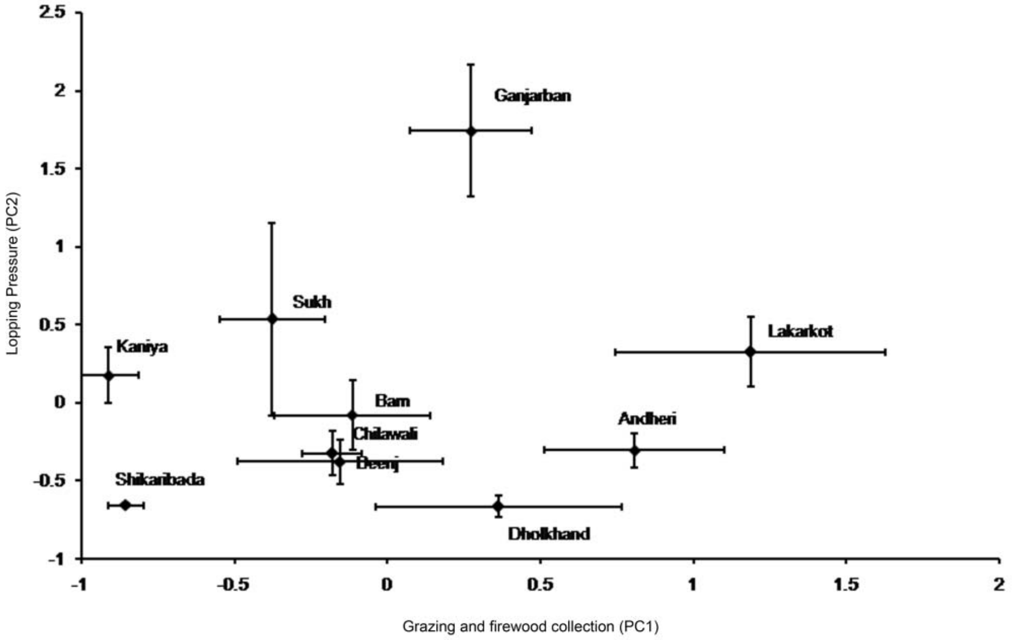

Fig. 3: Mean and standard error of two extractive disturbance components across different sampling plots

On correlating the vegetation variables (structural and compositional) we found that, percentage canopy cover was negatively related to grazing and firewood collection (PC1), whereas a strong positive relationship was observed between lopping pressure (PC2) and tree basal area. Interestingly, Lantana density also showed a significant positive relationship with lopping pressure. None of the vegetation attributes was found to be associated significantly with timber extraction (PC3). Both tree and shrub diversity did not show any significant relationship with any of the PCs (Table 2).

A total of 18 migrant and 66 resident bird species were detected within the study area across all the sampling plots over a two year period (Appendix 1). Richness of resident bird species was highest in the least disturbed plot of Shikaribada (41) and lowest in the moderately disturbed plot of Beenj (24). Highest richness of migrant birds was found in a moderately disturbed plot of Bam (13), and Beenj had the lowest migrant richness (4). Average density of migrants and resident birds for the study area was 2.9 ±0.08 (indi/ha) and 23.6 ±0.08 (indi/ha) respectively. Densities of both resident and migrant was highest in the disturbed plot Sukh (resident = 55.5 ±18.6, migrant = 22.9 ±20.6), and lowest in the moderately disturbed plot of Dholkhand (resident = 8.3 ±15.25, migrant = 3.3 ±20.4). The segregation of species in both the communities on the basis of their foraging guild revealed that resident birds had 11 guilds, whereas migrants belonged to only 6 guilds. Out of 18 migrant species observed during the entire study period, 44% belonged to understorey-insectivores guild and 33% to canopy-insectivores. Guild composition in resident birds was broader and trunk/bark feeder guild contributed the maximum number of species (20%) followed by understorey-insectivores (17%). However,

Table 2: Pearson's correlation between principal components of disturbance and vegetation (structural and compositional) variables

	Tree basal area (m^2)	Tree crown cover (m^2)	% canopy cover	Tree density	Shrub density	Shrub crown cover (m^2)	Lantana density	Shrub diversity	Tree diversity
PC1	0.17	-0.31	-0.65*	-0.19	0.40	-0.27	-0.09	0.29	0.04
PC2	0.81**	0.18	-0.29	0.27	-0.45	-0.01	0.67*	0.33	0.54
PC3	0.25	0.35	0.28	0.15	-0.20	0.11	0.27	-0.09	0.18

Statistically significant correlations between disturbance and vegetation variables are indicated with symbol* (*=$p<0.05$ and **=$p<0.01$)

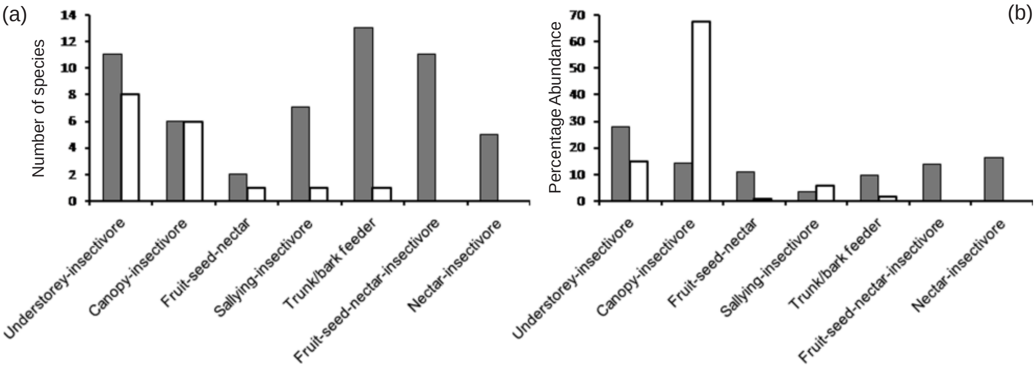

Fig. 4: Guild composition of resident and migrant bird species in terms of (a) species richness and (b) abundance

in terms of abundance, 67% of the migrants were canopy-insectivores and 14% were understorey-insectivores. Even in the resident bird community, 28% of the total abundance was contributed by understorey insectivores, followed by the canopy-insectivores (14%). For the graphical representation, we included guilds with more than 1% abundance (Fig. 4).

Both resident and migrant bird species richness showed declining trends with all the disturbance components, however, the results were not significant (Table 3). Densities of resident birds showed a declining but non-significant trend with grazing and firewood collection (PC1). A significant increasing trend was found between resident bird density and lopping disturbance (PC2), as well as timber extraction (PC3). Densities of migrant birds followed the same trend as resident birds, however, the relationship was only slightly significant for timber extraction (PC3, Fig. 5).

A positive correlation was found between the density estimate of migrant and resident species (r = 0.65, p = 0.04, Fig. 6a). Similarly a strong positive correlation was found between the resident and migrant species richness (r = 0.78, p=0.007) and diversity (r = 0.72, p=0.01, Fig. 6b).

DISCUSSION

Grazing and firewood collection were the major disturbance factors in the study area as they constituted the first principal component and explained the maximum variation in disturbance variables. Most of the different indicators used to quantify disturbance in this study were positively correlated with each other, which indicates concurrent nature of small-scale disturbances (Karanth *et al.* 2006; Martorell and Peters 2005; Singh 1998). Lopping pressure inside the Park depends largely on the availability of tree species preferred by Gujjars. However, areas preferred for lopping are not nececessarily subject to other disturbance activities. Therefore, lopping constituted a separate disturbance component.

In this landscape, disturbance intensities are influenced by flat terrain or accessibility, proximity to human habitation (Kurien *et al.* 2007) and degree of protection. In our study, we found that all disturbances declined as we moved deeper into the forest, which is coherent with other such studies (Karanth *et al.* 2006; Kurien *et al.* 2007; Thapa and Chapman 2010). Segregation of sampling plots across the first two principal

Table 3: Results of generalised linear model (GLM) for the resident migrant richness and density across different disturbance components

		Resident			Migrant		
Community attributes	Disturbance component	ß	SE	Z	ß	SE	Z
Richness	PC1	-0.003	0.09	-0.004	-0.01	0.17	-0.08
	PC2	-0.05	0.08	-0.65	-0.15	0.17	-0.90
	PC3	-0.27	0.18	-1.51	-0.56	0.35	-1.61
Density	PC1	-0.48	0.33	-1.4	-0.42	0.28	-1.50
	PC2	0.62	0.26	2.3*	0.43	0.25	1.72
	PC3	1.59	0.47	3.4*	1.01	0.51	1.95

Parameter estimate of the best model showing regression coefficient ±SE, z-statistics and significance (**= p= 0.001,*= p=0.01) components revealed that sampling plots such as Lakarkot and Ganjarban near the Park boundary suffered higher disturbance in terms of grazing, firewood collection, and lopping. In contrast, plots such as Shikaribada in the forested interior of the Park boundary experienced negligible disturbance.

Despite being cryptic, small extractive disturbances are known to bring severe changes in the habitat structure (Kumar and Shahabuddin 2005; Ramírez-Marcial *et al*. 2001; Sagar *et al.* 2003; Singh *et al*. 1997), which effects regeneration and stand composition (Beckage and Clark 2003). All vegetation structural variables did not show a strong relation with disturbance gradient, but a negative trend was evident for the foliage cover with first two disturbance components. Canopy opening and overgrazing lead to more sunlight reaching the forest floor and could decrease soil moisture and increase the temperature. Such overall increase in xeric conditions would be more detrimental for dry forest, as very few species would be able to cope with extremely high temperature and increased irradiance (Belnap 1995; Milton and Dean 1995; Valone *et al*. 2002). Enhanced understorey growth increases the fodder and firewood availability in open areas, therefore these areas showed higher disturbance due to grazing and firewood collection.

Canopy openings increase resource availability and also modify the microclimate, which is consistent with the disturbance patch invasion model (Gentle and Duggin 1997). According to this model, removal of competitive biomass and disruption of interspecific competitive interactions creates patches of increased resources. Many exotic weeds benefit from such disturbances and exert substantial pressure, including competition, on the native species (Fischer *et al.* 2006; Harper *et al*. 2005). In our study area, increased lopping pressure intensified Lantana density, supporting the disturbance patch invasion model. Such an increase in lantana cover will provide dense shade which would prevent establishment of herb and tree seedlings, eventually resulting in overall structural and compositional change in the forest (Sharma and Raghubanshi 2006).

Compared to migrants, residents showed a stronger relationship with disturbance variables. In addition, large scale disturbances such as timber extraction affected the resident bird richness more strongly than the small scale disturbances during winter. Insectivory appears to be the major foraging strategy during the winter, as the majority of migrants (90%) as well as the residents are insectivores. The majority of the resident birds appear to utilise the understorey vegetation layer

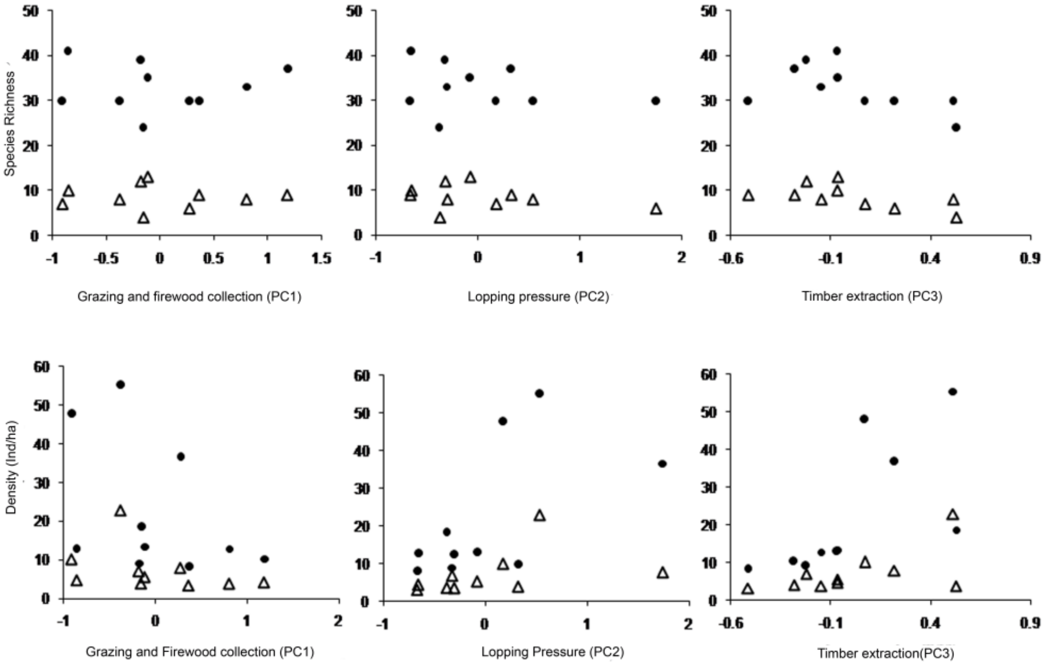

Fig. 5: Scatter plots between bird community parameters (richness and density) and extractive disturbance components. Resident bird community is represented by closed circles and migrant bird community by open triangles

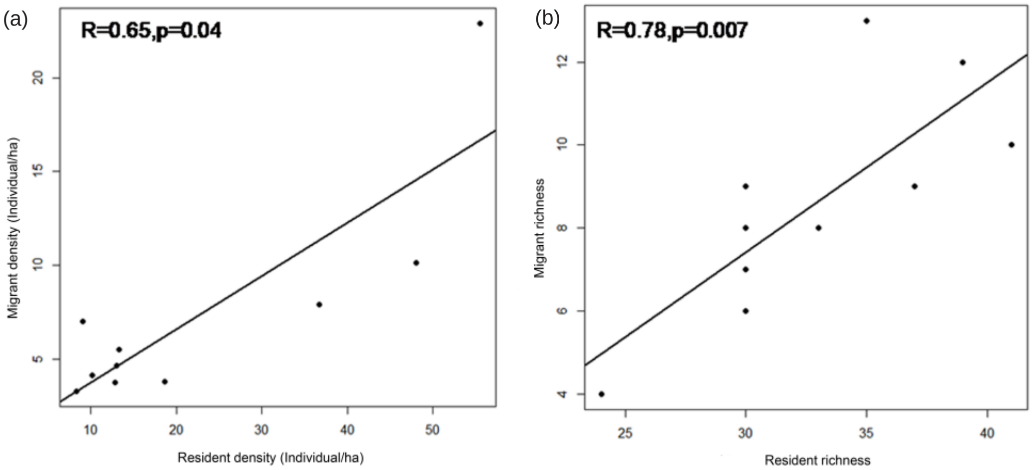

Fig. 6: Pearson Correlation between resident and migrant (a) density and (b) species richness

during the food-scarce winter season. This could be one of the mechanisms of accommodation of migrant birds during food shortage, as 67% of the migrant birds foraged in the canopy.

Past studies have suggested that migrants are more flexible than residents in their habitat use and are potentially more tolerant of disturbance (Greenberg 1995; Hutto 1989; Karr 1976). Yet there is evidence to prove that both migrants and residents share similar distribution pattern across habitat gradients (Emlen 1980; Petit *et al*. 1992). Smith *et al*. (2001) during their study in the Yucatan peninsula found that all stages of successional forest supported highly similar bird assemblages and did not differ in bird abundance or diversity. Moreover, residents and migrants distributed themselves similarly across successional gradients. Similarly, a study by Wallace *et al*. (1996) in the Cuban forest revealed that numbers of migrant and resident species were significantly positively correlated. Our study from Shiwalik landscape also follows a similar trend. Both species richness and density of migrant and resident birds were significantly positively correlated. This suggests that both resident and migrant birds might be equally tolerant or sensitive to disturbances.

Another possible explanation for the strong positive association between resident and migrant birds could be attraction between the two communities. Mönkkönen *et al*. (1990) hypothesized that migrants use resident birds as cues to profitable breeding sites and they called this phenomenon "heterospecific attraction". In experimental studies in boreal forests of North America and Europe, both richness and densities of migrants increased with increasing resident densities (Forsman *et al*. 1998; Mönkkönen *et al*. 1997). Similarly, a study conducted on resident Titmice and Pied Flycatcher in Finland showed that migrant flycatchers were attracted to the presence of Titmice and accrued benefits from this (Forsman *et al*. 2002). However, all studies on heterospecific attraction are conducted during the breeding season and there are no studies to verify this phenomenon in wintering sites. Still, it could be one of the most likely explanations for strong correlation between two bird communities. Such positive interaction between two potential competitors is suggested as highly beneficial for the migrants and neutral or beneficial for the residents (Forsman *et al*. 2002; Forsman *et al*. 2007; Mönkkönen and Forsman 2002). However, more studies on the interaction between resident and migrant birds in their wintering areas will strengthen our observation.

All these studies suggest that both migrant and resident bird species respond similarly to disturbance. These broad generalisations, however, should not be used for formulating conservation strategies for both groups. Different foraging guilds and individual species could vary significantly in their response to habitat disturbance, demanding specific conservation attention.

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Appendix 1: Bird species abundances recorded in 10 sampling plots in the dry forest of Rajaji National Park

Bird species	Sampling plots										Feeding Guild
Migrant Species	1	2	3	4	5	6	7	8	9	10	
Certhia himalayana	0	1	2	2	1	0	1	1	0	1	TBF
Anthus hodgsoni	8	5	0	0	0	0	0	39	9	0	GI
Phoenicurus coeruleocephala	0	0	0	3	0	0	0	0	0	0	UI
Saxicola ferreus	5	0	0	0	0	1	0	7	2	0	UI
Ficedula parva	4	2	0	8	3	0	1	8	0	0	UI
Ficedula strophiata	1	1	0	0	2	1	0	0	2	0	UI
Ficedula tricolor	0	4	0	2	0	5	0	0	2	3	UI
Phylloscopus fuscatus	0	2	0	0	0	0	0	0	0	1	UI
Seicercus whistleri	3	6	0	6	2	0	1	0	4	0	UI
Phylloscopus xanthoschistos	17	24	7	24	18	14	4	9	26	9	CI
Phylloscopus humei	24	30	15	30	27	6	16	24	35	27	CI
Phylloscopus chloronotus	1	0	0	8	3	0	1	2	0	0	CI
Phylloscopus tytleri	0	0	1	0	0	1	1	0	0	0	CI
Phylloscopus occipitalis	0	0	0	0	0	0	0	0	0	3	CI
Hypsipetes leucocephalus	0	0	0	3	0	0	0	0	0	0	GI
Culicicapa ceylonensis	0	6	0	6	4	0	0	1	8	11	SI
Sylvia curruca	0	4	0	3	0	0	0	5	1	0	CI
Zoothera dauma	0	0	0	0	0	1	0	0	0	0	UI
Resident species											
Spizaetus cirrhatus	0	0	0	0	0	0	0	3	5	0	R
Spilornis cheela	0	1	0	1	0	0	0	1	0	0	R
Accipiter nisus	0	0	0	0	0	1	0	0	0	0	R
Pernis ptilorhynchus	0	0	0	2	0	0	0	0	0	0	R
Accipiter badius	0	0	0	0	0	0	0	0	0	1	R
Aegithina tiphia	3	4	1	0	0	1	2	0	2	0	CI
Buceros bicornis	0	0	0	0	2	0	0	0	6	0	FI
Ocyceros birostris	0	0	0	2	0	1	0	2	0	0	FI
Anthracoceros albirostris	4	61	0	7	7	0	1	0	18	0	FI
Hemipus picatus	9	0	8	5	14	4	1	0	26	0	SI

Appendix 1: Bird species abundances recorded in 10 sampling plots in the dry forest of Rajaji National Park (*contd.*)

Bird species	Sampling plots										Feeding Guild
Migrant Species	1	2	3	4	5	6	7	8	9	10	
Coracina macei	0	0	0	0	0	0	2	1	4	0	CI
Pericrocotus flammeus	0	0	0	2	0	0	0	0	0	0	CI
Pericrocotus cinnamomeus	111	74	53	60	80	10	35	54	115	25	CI
Chloropsis aurifrons	0	2	0	0	0	0	0	0	0	0	CI
Orthotomus sutorius	7	10	2	3	0	2	2	6	3	1	UI
Prinia hodgsonii	182	64	59	98	62	21	64	157	50	32	UI
Chalcophaps indica	0	0	0	1	0	0	0	0	0	0	G
Corvus macrorhynchos	5	7	0	6	0	4	7	4	10	11	O
Urocissa erythrorhyncha	0	0	0	0	1	0	0	1	1	0	O
Dendrocitta vagabunda	4	12	7	18	3	3	4	15	16	14	O
Dicaeum erythrorhynchos	0	1	0	0	0	0	0	0	0	0	NI
Dicaeum agile	2	0	0	6	2	0	1	0	1	0	NI
Dicrurus macrocercus	0	0	0	0	0	0	0	2	0	0	SI
Dicrurus hottentottus	0	0	0	0	0	0	1	3	0	0	FSNI
Dicrurus caerulescens	7	3	3	8	3	1	3	0	5	12	SI
Halcyon smyrnensis	0	0	0	0	0	0	0	1	0	0	SI
Megalaima zeylanica	0	0	0	0	0	0	0	0	0	1	FI
Megalaima haemacephala	1	1	0	3	0	0	0	0	7	0	FSNI
Megalaima lineata	0	15	0	2	5	0	1	1	4	0	FI
Nyctyornis athertoni	0	2	0	1	0	0	0	0	0	0	SI
Saxicola caprata	0	0	0	0	0	1	0	0	0	0	UI
Cyornis tickelliae	1	9	0	0	0	1	1	3	2	2	SI
Copsychus malabaricus	1	0	0	2	0	0	0	0	0	0	UI
Aethopyga siparaja	1	3	0	2	4	2	0	2	4	0	NI
Nectarinia asiatica	0	0	0	2	0	0	0	0	0	1	NI
Oriolus xanthornus	1	9	2	7	7	14	8	5	6	7	FI
Parus major	41	27	18	32	59	11	17	25	27	17	TBF
Pavo cristatus	0	7	0	0	0	0	0	5	0	0	O
Lophura leucomelanos	0	0	0	0	0	0	0	0	2	0	UI
Gallus gallus	1	25	3	1	0	10	0	0	1	2	UI
Dinopium benghalense	5	3	1	5	2	1	4	3	5	1	TBF
Dendrocopos macei	3	3	0	9	1	3	3	2	6	2	TBF
Chrysocolaptes lucidus	0	0	1	6	4	0	0	5	1	1	TBF
Dendrocopos canicapillus	8	4	6	5	6	1	4	8	2	4	TBF
Picus canus	0	0	0	0	0	0	0	0	1	0	TBF
Dinopium shorii	0	0	1	2	0	0	0	0	0	1	TBF
Micropternus brachyurus	0	0	0	2	0	0	0	0	0	0	TBF
Picus sqamatus	0	0	0	0	1	0	0	0	0	0	TBF
Picus xanthopygaeus	2	0	0	1	0	0	1	1	0	0	TBF
Chrysocolaptes festivus	0	0	1	0	4	0	0	0	0	0	TBF
Psittacula cyanocephala	12	20	1	0	4	6	0	6	6	4	G
Psittacula krameri	68	50	77	43	32	30	68	78	23	3	FSN
Pycnonotus leucogenys	13	72	12	0	4	62	35	21	9	0	FSNI
Pycnonotus cafer	0	54	0	0	10	53	8	8	77	4	FSNI
Riphidura albicollis	5	4	0	4	2	0	1	1	4	7	SI
Sitta cinnamoventris	4	0	8	6	8	1	1	1	8	4	TBF
Sitta frontalis	0	0	3	1	1	0	1	0	3	0	TBF
Glaucidium radiatum	2	1	0	1	0	0	0	0	1	1	R
Acridotheres tristis	2	0	0	0	0	0	0	4	0	0	FSNI
Chrysomma sinense	0	0	0	0	0	10	0	0	0	0	UI
Tephrodornis pondicerianus	6	7	1	5	4	3	2	7	12	2	CI
Stachyris pyrrhops	2	9	0	0	0	4	0	4	4	12	UI
Turdoides striata	40	36	26	21	12	23	78	93	26	55	UI
Pellorneum ruficeps	0	2	0	0	0	0	0	0	0	0	UI

Appendix 1: Bird species abundances recorded in 10 sampling plots in the dry forest of Rajaji National Park (*contd.*)

Bird species	Sampling plots										Feeding Guild
Migrant Species	1	2	3	4	5	6	7	8	9	10	
Pomatorhinus erythrogenys	0	8	0	0	0	0	0	2	7	0	UI
Zosterops palpebrosus	88	274	15	62	89	9	44	22	66	87	NI

Sampling Plots: 1=Andheri, 2=Bam, 3=Beenj, 4=Chilawali, 5=Dholkhand, 6=Ganjarban, 7=Kaniya, 8=Lakarkot, 9=Shikaribada, 10=Sukh. Abbreviations used for Feeding guild: TBF=Trunk/bark feeder, GI=Ground insectivore, UI=Understorey insectivore, CI=Canopy insectivore, FI=Fruit insectivore, FSNI=Fruit seed nectar insectivore, FSN=Fruit seed nectarivore, SI=Sallying insectivore, NI=Nectar insectivore, O=Omnivore, R=Raptor

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