Diversity of Beetle on Oak (*Quercus lanata,* Smith*)* Canopy in Shivapuri National Park and Naudhara Community Forest, Nepal

Prakash Gaudel
T.U Registration No: 5-2-37-804-2008
T.U Examination Roll No: 21671
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Nepal

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DECLARATION

I hereby declare that the work presented in this thesis has been done by myself and has not been submitted elsewhere for the award of any degree. All sources of information have been specifically acknowledged by reference to the author(s) or institution(s).

Date: ……………………… ……………………….

Prakash Gaudel

Tribhuvan University

Central Department of Zoology

Kirtipur, Kathmandu, Nepal

RECOMMENDATION

This is to recommend that the thesis entitled "**Diversity of Beetle on Oak (*Quercus lanata,* Smith*)* Canopy in Shivapuri National Park and Naudhara Community Forest, Nepal**" has been carried out by Mr. Prakash Gaudel for partial fulfillment of Master's degree in Zoology with the special paper Entomology. This is his original work and has been carried out under my supervision. To the best of my knowledge, this work has not been submitted for any other degree in any institutions.

Date: ……………………………….

………………………………..

Supervisor

Indra Prasad Subedi

Lecturer

Central Department of Zoology

Tribhuvan University

Kirtipur, Kathmandu, Nepal

Tribhuvan University

Central Department of Zoology

Kirtipur, Kathmandu, Nepal

LETTER OF APPROVAL

On the recommendation of supervisor Mr. Indra Prasad Subedi, Lecturer, Central Department of Zoology, Tribhuvan University, the thesis entitled "**Diversity of Beetle on Oak (*Quercus lanata,* Smith*)* Canopy in Shivapuri National Park and Naudhara Community Forest, Nepal**" is approved for the examination and submitted to Tribhuvan University in partial fulfillment of the requirement for Master's Degree of Science in Zoology with special paper in Entomology.

Date: ……………….

……………………………………..

Prof. Dr. Ranjana Gupta

Head of Department

Central Department of Zoology

Tribhuvan University

Kirtipur, Kathmandu, Nepal

Tribhuvan University

Central Department of Zoology

Kirtipur, Kathmandu, Nepal

CERTIFICATE OF ACCEPTANCE

This thesis work submitted by Mr. Prakash Gaudel entitled "**Diversity of Beetle on Oak (*Quercus lanata*, Smith*)* Canopy in Shivapuri National Park and Naudhara Community Forest, Nepal**" has been accepted as a partial fulfillment for requirement of Master's Degree of Science in Zoology with special paper Entomology.

EVALUATION COMMITTEE

…………………………….

Supervisor
Indra Prasad Subedi
Lecturer
Central Department of Zoology
Tribhuvan University
Kirtipur, Kathmandu, Nepal

………………………….

Prof. Dr. Ranjana Gupta
Head of Department
Central Department of Zoology
Tribhuvan University
Kirtipur, Kathmandu, Nepal

……………………………………

External Examiner
Dr. Ishan Gautam
Natural History Museum
Swayambhu, Kathmandu, Nepal

Date: …………………………………..

………………………………

Internal Examiner
Dr. Daya Ram Bhusal
Lecturer
Central Department of Zoology
Tribhuvan University
Kirtipur, Kathmandu, Nepal

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Prakash Gaudel

Prakash.gaudel2@gmail.com

ABSTRACT

A survey of canopy beetle was conducted during June 2014 to March 2015 in Shivapuri National Park and Naudhara Community Forest. The study was focused on the diversity of canopy beetle associated with oak (*Quercus lanata*), comparing diversity between two study sites and to study various environmental factors (temperature, canopy cover, distance from human settlement, dead wood volume, history of host plants, canopy size and DBH) affecting the canopy beetle diversity. Eighteen canopy trap of 60 × 40 cm (height ×width) on each study area were used for beetle sampling. A total of 345 individuals of beetle belonging to 15 families were recorded from two study sites. Scarabaeidae was the dominant family contributing 171 individuals followed by the families Buprestidae, Curculionidae and Lucanidae contributing 34, 20 and 16 individuals respectively. Generalized Linear Model (GLM) with Poisson distribution and log link function was used to find factors affecting diversity of beetle. Multivariate test was carried using unimodal technique (CCA) to generate the relationship between environmental factors and beetle families and the significance was tested by performing Monte Carlo permutation test. The beetle occurrence was high during March, June, July and August. It was found that there were no beetle recorded during January, very few during February. Abundance of beetle were positively significant with distance from human settlement, deadwood volume, and history of host plant. Naudhara Community Forest was found to be flourishing more beetle diversity than Shivapuri National Park.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviated forms	Detail of abbreviation
BCN	Bird Conservation Nepal
CCA	Canonical Correspondence Analysis
DBH	Diameter at Breast Height
DPR	Department of Plant Resources
GPS	Global Positing System
IBA	Important Bird Area
Prof.	Professor
GLM	Generalized Linear Model
%	Percentage
Asl	Above sea level
et al.	and others
˚C	Degree Celsius
m	Meters
mm	Millimeters
spp.	Species
ie	That is

1. INTRODUCTION

1.1 Beetle in general

Coleoptera is the most species-rich and prevalent insect taxon worldwide which contribute to great biodiversity in forest habitats and play various roles in ecosystem dynamics and functioning (Lassau *et al.*, 2005). Among them are numerous forest pests (e.g. Scolytidae, Curculionidae), as well as effective predators (e.g. Carabidae, Cleridae, Coccinellidae) capable of bio-control (Reeve, 1997). Only few current studies exist that directly compare beetle communities of different tree species (Wagner, 2000; Hulcr *et al.*, 2007). Due to host specificity (Erwin, 1982; Stork 1988) and habitat preferences, species-rich forests can be expected to exhibit a greater diversity of beetle species, and in experimental forest habitats, tree diversity has been shown to affect positively arthropod species richness (Vehvilainen *et al.*, 2008). For example, many saproxylic beetle (e.g., Cerambycidae and Buprestidae) species, inhabit wood near the forest floor as larvae but utilize resources high in the canopy as adults (Wermelinger *et al.*, 2007; Schmidl and Bussler, 2008).

1.2 Oaks in general

Quercus (Oak), is a genus under the family Fagaceae with about 600 species globally (Shrestha, 2003). Oaks are a large group of hardwood trees and are found in the northern temperate zone, subtropical and tropical Asia, and the Andes of South America. Oaks dominate many forest landscapes and are intimately linked with a large number of other organisms, ranging from fungi to ferns, birds to bears, and wasps to ants (Shrestha, 2003). Oaks dominate the canopy in many temperate forests of the Himalayan region and oak forests are characterized by higher species diversity, stratification, litter production and soil fertility in comparison to other forests such as pine (Shrestha, 2003). Moreover, the bark of mature trees supports a luxurious growth of non-vascular as well as vascular epiphytes. Many oaks are keystone species without which the complex web of the ecosystem would soon unravel where oaks also promote the recharge of mountain springs (Valdia, 1998).

Himalayan oaks are evergreen, medium- to large-sized tree, distributed at elevations of 800 to 3800 m asl throughout the Himalayan region with more than 35 species reported from this region (Negi and Naithani, 1995), most of which are abundant in temperate forest. Eight species occur in Nepal (DPR, 1997): *Q. floribunda* Lindl, *Q. glauca* Thunb., *Q. lamellosa* Sm., *Q. lanata* Sm., *Q. leuchotrichophora* A. Camus, *Q. mespilifolioides* A. Camus, *Q. oxyodon* Miq. and *Q. semecarpifolia* Sm. The economical and ecological values of oak are generally higher than those of other species associated with oak. It is closely linked with hill agriculture as an important source of fodder for animals, litter for making compost, fire wood and timber. The regenerative capability of this *Quercus* spp. in the Himalayan region is poor and some of the reasons that explain the poor regeneration of oak forest are erratic seed production, defoliation, acorn herbivory, browsing damage to seedlings, forest fire, extensive lopping, accumulation of thick litter with slow decomposition rate, infestation by stem parasites such as mistletoe, and leaf damage by insect pests (Shrestha, 2003).

1.3 Epiphytism and Epiphytic plants in general

Epiphytic plants are diverse and can create important microcosms for many other organisms, including micro-organisms, insects, birds and mammals, which are rarely encountered on the floor. Epiphytism is shown by plants that grow upon another plant usually a shrub or tree at least for part of its life cycle. Epiphytism is for support and exposure to sunlight, water and nutrients that are to be absorbed through their absorbing roots which are provided with green tissue surrounded by velamen and epidermis acting as sponge. There may be several important differences between epiphytes and terrestrial habitats where light and moisture availability is one important difference. Better exposure to pollinators, seed dispersal and avoidance of slugs and other terrestrial herbivores, may be favorable aspects of the epiphytic habitat (Madison, 1977). Most of the tropical species have epiphytic habit and are characterized by long roots which are used to hold them to their host and to collect nutrients from around their root system and also moisture from the air. Some epiphytes are provided with fleshy pseudobulbs, which acts as storehouse to help in perennation during dry season. Epiphytism occurs in 65 different families of vascular plants, involving about 850 genera and nearly 30,000 species of which about 500 genera and 20,000 species belong to orchid alone (Madison, 1977).

Orchids are diverse groups of flowering plants which belong to family Orchidaceae, in the plant group the Monocotyledon (Ghimire, 2008). Orchids may differ from other plants by the mode of growth and morphological characters possessed by its members with two modes of growth: i. Sympodial growth: refers to the pseudobulbs or stem being jointed by a rhizome, and ii. Monopodia growth: refers to the plant having no pseudobulb and have a single shoot producing leaves alternately. Epiphytic orchids are those found growing upon the bark of other trees or shrubs at least part of their life cycle and always have drooping inflorescence. The orchid family is the second largest family after Asteraceae in the flowering plant and it is estimated that more than 850 species of orchids are existing in the Himalayan region (Acharya *et al*., 2011) with 437 species in Nepal alone (Rokaya *et al*., 2013). In Nepal, in term of species richness, Orchidaceae is the largest family comprising 377 species under 100 genera (Rajbhandari and Dahal, 2004). About 185 species of epiphytic orchids have been reported by Rajbhandari *et al.* (1999) from Nepal. Due to orchids beautiful flowers, long blooming period, they have become great favorites in the horticultural trade and for internal decoration.

Tropical, subtropical to temperate regions (up to 3000m) are the best place for the epiphytic orchid diversity, as these belts represent almost all 205 species, among the total 207 epiphytic orchid species from the Nepal (Ghimire, 2008). A study conducted by Ghimire (2008) reports the host plant species important for epiphytic orchids (148 species) as *Schima wallichii*, *Quercus* spp. *(Q. glauca, Q. semicarpifolia, Q. lanuginosa, Q. griffithii etc.), Rhododendron* spp. (*R. arboreum, R. barbatum etc.) Shorea robusta,* and *Castanopsis spp. (C. indica, C. tribuloides* etc.) and they represent about 65, 42, 20, 18, and 18 species of epiphytic orchid respectively. Moreover, epiphytic orchids are mostly concentrated in Central (81 species) and Eastern (47 species) Nepal alone, whereas 9 species are found distributed throughout the country.

The ferns belong to a primitive group of vascular plants and contribute significantly to the number of species in the flora of tropical and sub-tropical mountains (Bhattarai *et al.*, 2004). In contrast to many woody plants, ferns are dispersed by means of small spores and establish new populations in distant localities, they exhibit less frequent speciation, they have a mostly herbaceous perennial growth form (a few are annuals and or tree-like), need moisture, and they have a long evolutionary history (Smith, 1972; Kato, 1993). Epiphytic ferns are adapted to a drier habitat than most terrestrial types. Epiphytic ferns naturally occur on the branches of trees in subtropical and tropical forests where they grow in a totally soilless condition without using the typical water and nutrient storage of soil. The plants obtain water and nutrients only during rain leached from tree leaves and are located beneath the canopy formed by the leaves of the trees where the leaves reduce the strong tropical sunlight. Thus, epiphytic ferns tolerate short periods of full sun but prefer strong filtered or reflected sunlight throughout the day.

1.4 Rationale

1.4.1 Justification of study

Despite being an important part of the forest ecosystem, studies on canopy beetle had never been documented in Nepal yet. Hence, documentation and exploring factors influencing the diversity of canopy beetle is important. It also highlights the relationship between beetle and associated plant species and also helps to find out abundance and their monthly variations over the period of time which is new research in Nepal.

1.4.2 Limitation of study

- There was weak preservation of specimens in rainy season due to dilution of preservative used.
- Identification was limited to family only due to lack of taxonomist crisis.

1.5 Objectives

1.5.1 General objectives

- To study the diversity of canopy beetle associated with oak (*Quercus lanata*) in Shivapuri National Park and Naudhara Community Forest.

1.5.2 Specific objectives

- To compare the canopy beetle diversity between Shivapuri National Park and Naudhara Community Forest.

- To study the various environmental factors (temperature, canopy cover, distance from human settlement, dead wood volume, history of host plants, canopy size and DBH) affecting diversity of canopy beetle in study sites.
- To study the effect of environmental treatments (no impact, orchid removed and fern removed) on beetle diversity of *Quercus lanata*.

2. LITERATURE REVIEW

Invertebrates are very common component of most terrestrial ecosystems and a key element in the energy flow and nutrient turnover within a community (Tassone and Majer, 1997). Arboreal invertebrates may function as major herbivores, pollinators, parasites and predators (Majer and Recher, 1988) and are themselves an important food resource for vertebrates.

The canopy of tropical trees was called the last biotic frontier in order to emphasize that this habitat harbours the most diverse terrestrial arthropod fauna on earth (Erwin, 1983). Until the early eighties of the last century the canopy was largely neglected in research and now the research is focused on tropical countries from the beginning (Köhler, 1992; Floren and Schmidl, 2008). Although the importance of biodiversity to the stability, resilience and productivity of forests is now widely recognized (Loreau *et al.*, 2002; Hooper *et al.*, 2005; Peuttmann *et al.*, 2009) most forest-dwelling species remain either undiscovered (May, 1988; Stork, 1988) unknown ecologically (Spence *et al.*, 2008) or of undetermined conservation status (Wilcove and Master, 2005). Because a large proportion of these organisms reside in the forest canopy, canopy research is essential for acquiring the holistic perspective needed to optimize conservation and management strategies (Moffett, 2000, 2001; Didham and Fagan, 2004).

Plant diversity plays an important factor of arthropod vertical distribution, with fewer tree species forests supporting fewer arthropods in the canopy than species rich forests (Sobek *et al.*, 2009b). As a result, arthropod communities appear to be more concentrated near the ground in forests consisting of few tree species than in more diverse forests (Pucci, 2008; Ulyshen and Hanula, 2007).

Among the many factors influencing forest height are age, site quality, tree composition and altitude (Aber, 1979). Forests become more horizontally complex with age where mature forests consisting of a mosaic of tree fall gaps at various stages of succession (Brokaw and Lent, 1999; Tanabe, 2002) and these open spaces greatly influence the vertical distribution patterns of arthropods and their predators, particularly those capable of flight (Didham and Fagan, 2004).

Forests with midstories trees have a highly layered appearance and these layers are likely to influence the dispersal heights of arthropods by creating flight paths (Smith, 1973). Many arthropod taxa are less numerous in the relatively open and less-vegetated trunk zone than in the upper canopy (Schroeder *et al*., 2009).

Foliage becomes less concentrated in the high canopy and more evenly distributed vertically (MacArthur and MacArthur, 1961) as forests age (Nadkarni *et al*., 2004) and tree species richness increases (Ishii *et al*., 2004a) thereby enhancing and promoting microhabitat isolation within arthropod communities (Tanabe, 2002). Moreover, intra-crown leaf area index decreases as trees age, with important consequences for within-canopy gradients (Nock *et al*., 2008). While studies have shown many arthropod orders become less abundant, species rich or diverse with height above the forest floor (Hacker and Muller, 2008; Hirao *et al*., 2009) the highly stratified nature of these arboreal communities becomes recognizable with increasing taxonomic resolution (Savage *et al*., 2008; Gossner, 2009).

Time is one of the greatest sources of variability with respect to arthropod vertical distribution (Didham and Springate, 2003). The canopies of old forests contain a greater variety of habitats and resources than those of young forests (Ishii *et al*., 2004b) and support more diverse arthropod faunas (Floren and Schmidl, 2008; Horstmann and Floren, 2008). Tree cavities can be found throughout the canopy but generally decline in size with height and age of plant, with important associations for arthropod occurrence (Kitching, 1971). Several studies from Europe have shown many species of beetle families (e.g., elaterids, tenebrionids, scarabaeids) to be more abundant in elevated cavities than in those closer to the ground with species richness increasing with height (Ranius, 2002).

Recent work by Fritz (2009) demonstrates the importance of old trees in maintaining diverse epiphyte communities. Epiphytes provide food, shelter; hunting grounds and camouflage for diverse terrestrial arthropods and invertebrate faunas and the vertical distributions of these organisms depend on their specific epiphyte associations and other habitat requirements (Stubbs, 1989; Prinzing and Wirtz, 1997). Old tree bark provides important epiphytes habitats for a specialized fauna (Nicolai, 1986, 1993; Szinetár and Horváth, 2005; Pinzon and Spence, 2010). In central Europe, Nicolai (1986) found that rough-barked tree species had about twice the diversity and evenness of arthropods as smooth-barked tree species, including a number of species dependent on rough bark. Because tree bark unavoidably becomes rougher and more epiphyte-laden with age, and old trees provide more canopy habitats than young resulting in greater importance to bark dwelling arthropods (Fritz, 2009).

More than one fifth of all forest-dwelling arthropod species are saproxylic (Elton, 1966; Grove, 2002). Although all dead wood eventually falls to the ground, much of it begins in the canopy in the form of standing dead trees as snags, dead branches and twigs, and rotting heart wood (Fonte and Schowalter, 2004). While these resources support fewer saproxylic arthropod species than wood on the forest floor, community composition changes considerably with vertical position, with many species preferring standing or suspended wood (Hammond *et al.*, 2004; Franc, 2007; Ulyshen and Hanula, 2009; Vodka *et al.*, 2009; Bouget *et al.*, 2011). Many arthropods, particularly beetle, are known to be attracted to dark vertical shapes in the trunk zone and more readily attack upright dead, dying or weakened trees than fallen trees. Franc (2007) found this to be particularly true for wood boring beetle species attacking oaks in Sweden. Species occupying the same snag often exhibit vertical stratification (Ulyshen and Hanula, 2009) and many species known to infest branches and twigs are more common in the crowns of over story trees (Ulyshen and Hanula, 2007, 2009; Bouget *et al.*, 2011).

For canopy beetle, community interaction takes place in individual tree crowns (Gering and Crist, 2002) and sample-based a-diversity can be utilized as a snapshot of this community at a given time. Ranius and Jansson (2000) studied beetle species associated with old oaks in south-eastern Sweden and assessed the influence of forest regrowth, tree size and original canopy cover on the species richness of saproxylic beetle where a total of 120 saproxylic beetle species associated with mature or old oaks were identified and the occurrence of 68 saproxylic beetle species in particular was noted and the species richness was greatest in stands with large, free-standing trees where large girth as well as low canopy cover increased frequency of occurrence for several species and forest regrowth was found to be detrimental for many beetle species.

Southwood *et al*. (2004) made a study of the arthropod fauna of two native oaks (*Quercus petraea* and *Q. robur*) and of two introduced species (*Q. cerris* and *Q. ilex*) in woods near Oxford, U.K., and of two native species (*Q. ilex* and *Q. pubescens*) in southern France by knockdown sampling and branch clipping for the duration of five years in England and four years in France and concluded that species richness were similar for the two native oaks in U.K. whereas the fauna of the evergreen *Q. ilex* had a similar species richness both in France, where it is native and in England as introduced, and where its phytophage association was smaller than that of the deciduous species. In England a marked seasonal pattern was observed in all years: chewing insects peaked in May, followed sequentially by sucking species, leaf miners and gall formers. Most phytophages were much less abundant on the introduced oaks than on the native species.

Stork and Grimbacher (2006) conducted a four-year beetle sampling program in lowland tropical rainforest in North Queensland, Australia by using a trap that combines Malaise and flight interception trap functions where a pairs of this trap was suspended one on the ground and a second 15-20 m above in the canopy at five sites, with tree spaced 50 m or more apart and these traps produced 29,986 beetle of 1,473 species and 77 families with similar numbers of individuals (canopy 14,473; ground 15,513) and species (canopy 1,158; ground 895) in each stratum, but significantly more rare species in the canopy (canopy 509; ground 283) showing that The canopy and the ground strata both provide important contributions to rainforest biodiversity. Moreover, seventy two percent of the species, excluding rare species, were found in both strata and by using IndVal, they found 24 and 27% of the abundant species ($n \geq 20$ individuals) to be specialized to the canopy and the ground strata, respectively, and equivalent analyses at the family level showed figures of 30 and 22%, respectively.

Sprick and Floren (2007) conduct an investigation of arboreal phytophagous beetle from primeval forests and managed forests of Białowieza and Borecka Forests by insecticidal knock-down and revealed that the samples from ancient woodland, primary forest sanctuaries, and different-aged managed forest have contributed to 129 phytophagous beetle species and 24458 individuals of the families Chrysomelidae, Bruchidae, Anthribidae, Rhynchitidae, Attelabidae, Apionidae, Nanophyidae, and Curculionidae from the area of Białowieza Forest where 78 fogging samples was from common oak (*Quercus robur* L.), 28 from spruce (*Picea abies* (L.) KARST.), 13 from hornbeam (*Carpinus betulus* L.) and 3 from different trees (*Acer platanoides* L., *Populus tremula* L., *Pinus sylvestris* L.) and 25 species and 1531 individuals of beetle from the area of Borecka Forest where 11 trees were fogged (3 *Quercus robur L.*, 4 *Picea abies*, 3 *Carpinus betulus* and 1 *Tilia cordata* MILL.).

Ulyshen and Hanula (2007) compared the beetle fauna captured in a temperate deciduous forest of the southeastern United States with the help of 12 pairs of flight intercept traps suspended at two different heights above the ground (≥15 m and 0.5 m) where they reported a total of 15,012 beetle specimens representing 73 families and 558 morphospecies with three families Cerambycidae, Cleridae and Coccinellidae more abundant and species rich in the canopy, whereas four other groups Carabidae, Pselaphinae (Staphylinidae), Scolytinae (Curculionidae) and other Staphylinidae more abundant and species rich near the ground and witnessed that Shannon's diversity and evenness were both higher near the ground than in the canopy, but no differences in total abundance or species richness between the two layers.

Vodka *et al.* (2009) studied habitat preferences of two beetle families, Buprestidae and Cerambycidae, by the beetle using standardized oak timber baits, exposed to ovipositing females in alluvial woodlands of Southern Moravia, Czech ,within a landscape of managed hardwood forests and meadows with old solitary trees where the baits were made of freshly cut oak (*Quercus robur*), each weighting 15–20 kg and was 1 m long, consisting of 2–3 pieces of stem (diameter 8–12 cm), 2–3 thicker branches (3–8 cm), 4–8 thinner branches (1–3 cm) and a bunch of twigs and reared a total of 2,605 beetle individuals in 22 species (Buprestidae: 374, Cerambycidae: 2,231) where these numbers correspond to 8.8 individuals per 1 kg of wood and reported that local dead wood volume had no effect and there was a high preference for sun exposed wood located near the ground suggesting the policy of increasing dead wood volume in commercial forests is principally correct and oak-utilizing xylophages would be benefited from restoration of management practices such as coppicing or woodland pasture.

To facilitate monitoring of Coleopteran diversity, indicators at the family level that adequately represent the beetle diversity Ohsawa (2010) placed one Malaise trap in each of 52 forest stands and distance between the trap ranged from 0.2 to 14.5 km in the central mountainous region of Japan where 12,099 beetle individuals belonging to 869 species and 76 families were captured and the relationship between the species composition of each family and the overall composition of all families was examined using Mantel tests where families with high correlation coefficients for species richness included Cerambycidae, Cleridae, Curculionidae, Lycidae, Elateridae, families exhibiting strong similarity in composition to the composition of all families were Scolytidae, Elateridae, Curculionidae, Cerambycidae, and Staphylinidae and the Cerambycidae, Curculionidae, and Elateridae were determined to be useful surrogates for Coleopteran diversity.

Ulyshen (2011) studied the vertical distribution patterns of arthropods in temperate deciduous forests and concluded that they are unevenly vertically distributed communities where these patterns are determined by time (forest age, season, time of day), forest structure (height, vertical foliage complexity, plant surface textures, tree cavities), plant community composition (plant diversity, invasive species),climatic gradients (light exposure, temperature, wind speed, humidity), resource availability (foliage, sugars, wood, epiphytes, carrion, dung, prey, hosts, mates), inter-specific interactions (predation, interference, competition) and logistics (dispersal abilities, proximity to emergence sites, open flight zones). Protecting large diameter trees and snags is also important, especially for a wide variety of canopy arthropod taxa associated with standing or suspended dead wood, tree cavities and epiphytes.

In a lowland forest of northern Italy, Hardersen *et al*. (2014) used Malaise traps in the canopy and ground layer and eleven beetle families (Buprestidae, Eucnemidae, Throscidae, Elateridae, Cantharidae, Dasytidae, Malachiidae, Tenebrionidae, Cerambycidae, Anthribidae, and Scolytidae) were collected and species richness and similarity of assemblages were compared explaning that the beetle assemblages in the two layers were significantly different, but species richness was similar. Moreover, this study showed that the distribution of beetle in the forest was structured in time and space and that season influences the capacity to distinguish between beetle assemblages sampled in the canopy and at the ground.

3. MATERIALS AND METHODS

3.1 Study Area

Shivapuri National Park (27° 45' to 27° 52' N and 85° 15' to 85° 30' E) with an area 159 km^2 and altitude ranging from 1366 m to 2732 m asl. was selected for beetle sampling. It lies at about 12 km away from the capital city on the northern fringe of Kathmandu valley. The area is prominent with subtropical and temperate type of vegetation. The subtropical zone is dominated by *Schima wallichii*, *Castanopsis indica*, *C. tribuloides* and *Pinus roxburghii* and at higher elevations, mixed temperate forest of oak (*Quercus lanata*, *Q. semecar pifolia*) and Rhododendron (*Rhododendron arboreum*) are predominant (Chaudhary, 1998). Dahlen (1993) classified this area into three distinct types of forests along the altitudinal gradients, *Pinus roxburghii* forest (1600 m - 1800 m), *Quercus – Castanopsis- Rhododendron forest* (1900 m - 2300 m) *and Q. semecarpifolia Rhododendron arboreum* forest (2400 m – 2732 m). Moreover, Sigdel (2008) reported *Rhododendron abroreum* and *Quercus lanata* tree species to be dominant at middle altitudinal range (1900 m - 2300 m) at Shivapuri Nagarjun National Park.

Naudhara community forest lies within Phulchoki hill, was taken for the study. Phulchoki hill (27° 33'N, 85° 22'E), lies at an altitude upto 2307 m asl. and 16 km southeast of Kathmandu, Nepal. It is a part of sub-Himalayan Mahabharat region with an altitudinal range of 1400 m to 2715 m with extensive diverse forests mostly dominated by broad leaved evergreen trees. It covers an area of approximately 50 square km consisting of a vast range of flora and the vegetation of Phulchoki hill and is characterized by three distinct evergreen broad leaved forest types: mixed *Schima castanopsis* forest at the base (1400 m to 1800 m), Oak- Laurel forest (1800 m to 2400 m) and evergreen oak forest (2000 m above) (Kattel *et al.*, 2015). The area is recognised by Bird Conservation Nepal (BCN, Bird Life International's Partner in Nepal) as an Important Bird Area (IBA) on account of its importance for the restricted range bird species, Spiny Babbler *Turdoides nipalensis* (Nepal's only endemic breeding bird) and Hoary throated Barwing *Actinodura nipalensis* (BirdLife International, 2013). Other species of significance include the Golden Emperor butterfly *Dilipa morgiana*, Leopard *Panthera pardus* and many threatened orchids. Phulchoki IBA covers 4281 ha, one third of which is managed as community forests (1368 ha), and the rest (mainly on and around the summit) is national forest.

The study area has typical warm temperate monsoon climate with three seasons round the year: cold and dry winter (October to February), pre monsoon dry summer (March to May) and monsoon (June to September) and the mean temperature ranges between 2.6 to 18.7 °C in winter and 15.8 to 28.2 °C in summer with mean annual rainfall is 1882 mm with about more than 80 percent between mid-June to mid-September (Kattel, 2015). Relative humidity at 6:30 am is greater than 90 percent in July, with a minimum of 63 percent in April (Poudyal, 2013). The natural climax vegetation of the hill is a mixed leaved forest (subtropical vegetation) dominated by *Schima wallichi* and *Castanopsis indica*. In the surrounding hills, Oaks-laurel forest occurs, many deciduous species, conifers and the pine forest can be seen in many hill locks with upper hill consists of temperate type of vegetations.

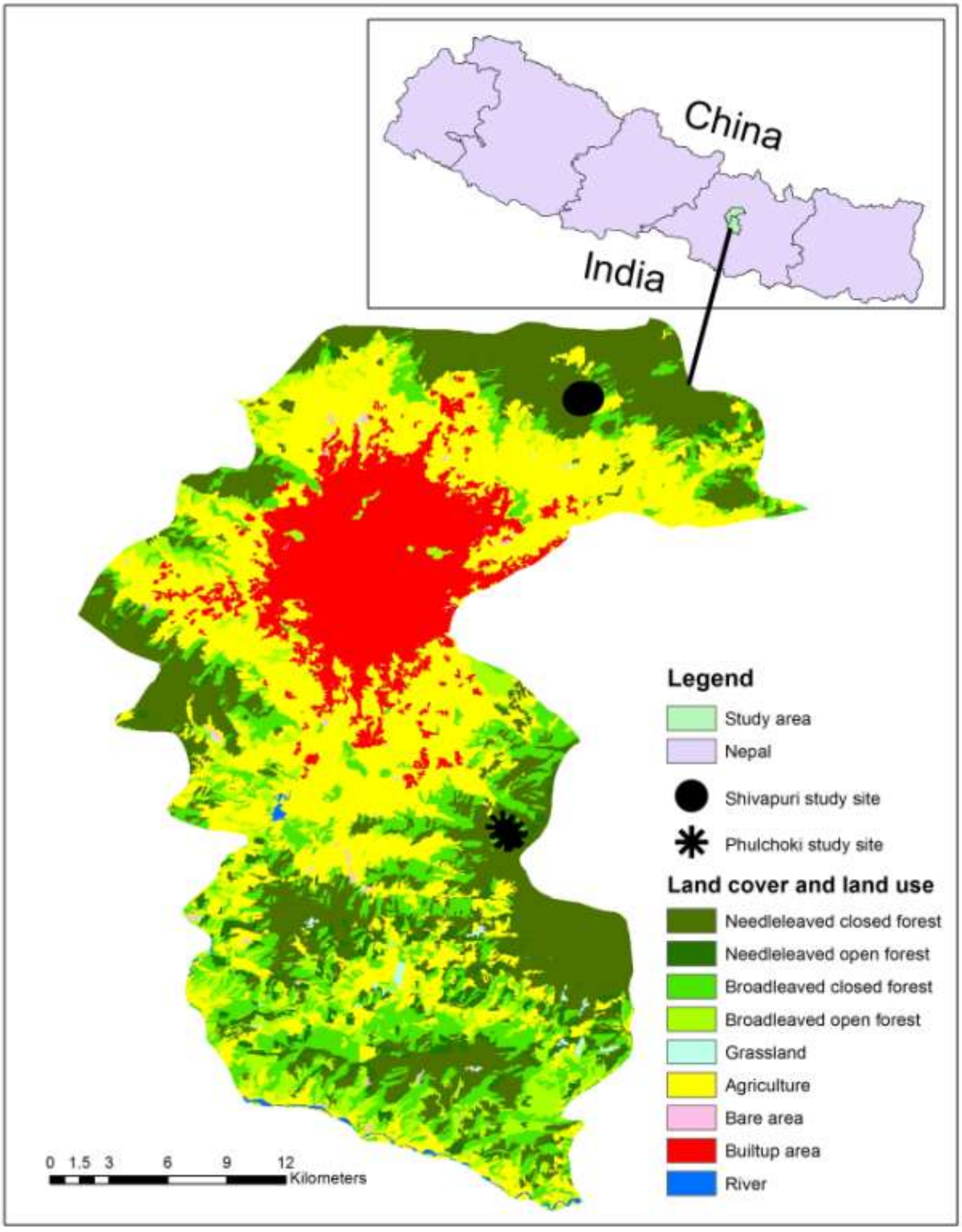

Figure 1: Study Area

3.2 Materials

3.2.1 Canopy trap

A composite flight interception traps consisting of crossed transparent plastic shields (60×40 cm) with funnel of smooth plastic cloth attached to the bottom filled with preserving liquid was used to collect canopy beetle.

3.2.2 Global Positioning System (GPS)

Garmin eTrex 10 GPS was used for acquiring the location of oak trees.

3.2.3 DBH meter

DBH meter was used to measure the diameter of sampled trees at breast height.

3.2.4 Rope

The rope was used to hold canopy traps high in the tree canopy branches.

3.2.5 Collection Jars

Transparent plastic bottles were used to collect the samples from study sites.

3.2.6 Magnifying glass and Microscope

Magnifying glass and simple microscope were used to explore the morphological characters of beetle during the course of identification.

3.2.7 Camera

Nikon D5200 with 18-55mm VR lens was used to photograph the specimen.

3.3 Sampling method

3.3.1 Sampling:

Eighteen possible oldest trees of *Quercus lanata* were selected randomly on each forest type. The information about the history of the stand and age of host trees were obtained from old people living near the forest. An epiphyte removal experiment was applied to study the functional interaction between epiphytes and beetle and to compare natural diversity of crown dwelling beetle in national park with diversity of same group in community forest.

Three epiphyte treatments were implicated one meter around the trap i.e. no impact on epiphytes (1), orchids removed (2), fern removed (3) with six replications of each treatment. The trees were tagged with a code for identification.

The tree with no impact on epiphyte were wrapped with red ribbon for easy visual recognition and tagged as Qm11, Qm12, Qm13, Qm14, Qm15 and Qm16 for managed forest and Qn11, Qn12, Qn13, Qn14, Qn15 and Qn16 for natural forest. Here Qm11 represents *Quercus* plant of managed forest of treatment 1 (i.e. no impact on epiphytes) with replication no 1.

The tree with orchids removed were wrapped with yellow ribbon and tagged as Qm21, Qm22, Qm23, Qm24, Qm25 and Qm26 for managed forest and Qn21, Qn22, Qn23, Qn24, Qn25 and Qn26 for natural forest. Here Qm21 represents *Quercus* plant of managed forest of treatment 2 (i.e. removal of orchid) with replication no 1.

The trees with fern removed were wrapped with blue ribbon and tagged as Qm31, Qm32, Qm33, Qm34, Qm35 and Qm36 for managed forest and Qn31, Qn32, Qn33, Qn34, Qn35 and Qn36 for natural forest. Here Qm31 represents *Quercus* plant of managed forest of treatment 3 (i.e. removal of fern) with replication no 1.

3.4 Field survey, Beetle collection, preservation and identification

The chosen trees were supplied with a canopy trap suspended at the height of 10-15 m depending on tree height in the canopy by using pulleys and ropes attached to big branches in the crown of a large *Q. lanata* trees, at maximum of 15 m from the centre of the square grid (Sobek *et al*., 2009a; Gossner *et al*., 2013; Meng *et al*., 2013). Beetle were collected using two pieces of transparent plastic plates (60 × 40 cm, height × width) which were arranged crosswise and fixed upon a red plastic bowl of 40 cm in diameter from upper surface and a collecting jar filled with ethylene-glycol as a preservative liquid (Sobek *et al*., 2009a; Meng *et al*., 2013) at the bottom. All the traps were installed in the individual tree crowns using a crossbow. Sampled trees were randomly selected in a 10 m wide corridor in the directly adjacent forest and clearance of traps was accomplished every 1 month over a period of 10 months from June 2014 to March 2015 where beetle were separated from plant material and other debris and stored in 90% ethyl alcohol (Sobek *et al*., 2009a) and all individuals were assigned to taxonomic levels (families). Alcohol-preserved specimens were deposited in Natural History Museum, Tribhuvan University, Swayambhu. Though various arthropods were collected in the trap, the study was focused on the order coleoptera (beetle).

Collected beetle individuals were identified by using keys from Johnson and Triplehorn (2004). Specimen comparison was also performed with the beetle specimens of Natural History Museum. Further confirmation was done with beetle expert Puspa Keshari Shrestha, retired Associate Professor, Natural History Museum, Tribhuvan University, Swayambhu.

3.5 Data analysis

Data on species richness and composition of beetle communities (according to family not as each species) were carried out. To find out the determinants of abundances, occurrences (presence or absence in each tree species) and the number of family of different coleoptera, Generalized Linear Model (GLM) with Poisson distribution and log link function was used. First, it was tested if there was significant effect of month. In case month was significant, it was used it as a covariate and tested the effect of different environmental variables (average monthly temperature, distance from human settlement, deadwood volume, history of plant, diameter at breast height or DBH of each tree, height of trap, size of tree crown, canopy cover, bark pH). A forward step-wise analysis to select other explanatory variables with the highest explanatory power based on Akaike Information Criterian (AIC) value. Finally, the data set was analysed with a model with all the explanatory variables with highest explanatory variables having significant value and the treatment used in every tree (which was supposed to additional factor to influence beetle). The model was selected by using Akaike Information Criterian (AIC). The analyses were carried out using S-Plus (S-Plus, 2000).

Multivariate tests for composition of coleoptera communities were carried using unimodal technique (CCA) because there was long gradient length of 5.6. (Lepš and Šmilauer 2014). The model was built sequentially in the same way as for above mentioned univariate (i.e.GLM) analysis. The significance was tested by performing Monte Carlo permutation test as available in software. All tests were carried out using Canoco 5.04 (ter Braak and Smilauer, 2012).

4. RESULT

4.1 Diversity of beetle and factors affecting diversity and composition of those beetle in two kinds of forests

During the study period, 345 individuals of beetle belonging to 15 families were recorded from two study sites. NCF contributed highest majority of families (i.e. 14) whereas SNP had only 6 families recorded. In both the study sites, family Scarabaeidae was found the predominant family (Figure 2).

The abundance of beetle was found significantly correlated with the months. The families of different beetle types were significantly variable according to months (Table 1). June was the high abundance month whereas November, December and February were the less beetle observed months of beetle recorded (Table 1, Figure 3). In January, April and May there was no beetle recorded. The abundance of beetle was found positively correlated and significant with temperature. Highest abundance of beetle was recorded at 18 ˚C to 21 ˚C and less abundance was occurred at 8 ˚C to 10 ˚C (Table 1, Figure 4). Moreover, abundances of beetle were positively significant with distance from human settlement (Table 1, Figure 5), deadwood volume (Table 1, Figure 6) and tree canopy size (Table 1, Figure 7). Unlike the above trend, the abundance decrease with increase of size of DBH (Table 1, Figure 8) and canopy cover (Table 1, Figure 9). There was no effect of different environmental treatments (no impact, orchid removed and fern removed) (Table 1). The occurrence of different beetle was partially higher in *Quercus* forest than *Castanopsis-Tribuloides* forest (Table 1). The history of the host plant was selected by forward tests but was not significant because of that this factor has some effect on abundance of beetle in this study. Other environmental variables (size of tree crown, vegetation) does not had any effect for occurrences of beetle.

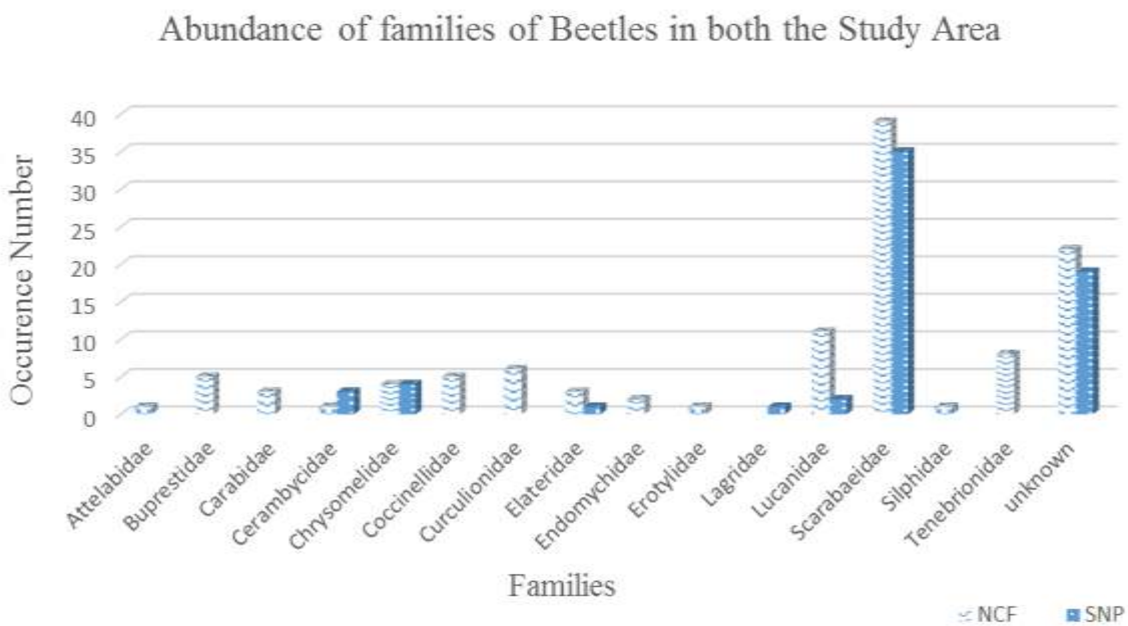

Figure 2: Abundance of canopy beetle in Naudhara Community Forest (NCF) and Shivapuri National Park (SNP)

Table 1**:** Tests showing the beetle associations in Nepal between abundance, occurrences, number of families and species composition of different beetle and various environmental variables tested by Generalized Linear Model (GLM). The values marked in bold are significant (p<0.05). Dash (-) means values were not selected by respective testes

		Abundance of Beetle		**Occurrences of Beetle**		**Families of Beetle**		**Species composition of Beetle families**	
	Df	**Pr(Chi)**	**R^2**	**Pr(Chi)**	**R^2**	**Pr(Chi)**	**R^2**	**P-value**	**% explained by canonical axis**
Month	8	**<0.001**	0.225	-	-	**<0.001**	0.461	-	-
Average monthly temperature	1	**0.021**	0.019	-	-	-	-	0.084	1.6
Distance from human settlement	1	**0.011**	0.023	-	-	-	-	**0.018**	2.2
Dead wood volume	1	**0.001**	0.041	-	-	-	-	-	-
History of host plant	1	**0.528**	-	-	-	-	-	**0.054**	1.7
Diameter at breast height (DBH)	1	**<0.001**	0.079	-	-	-	-	-	-
Size of tree crown	1	**<0.001**	0.064	-	-	-	-	-	-
Canopy cover	1	**0.029**	0.017	-	-	-	-	-	-
Vegetation	1	-	-	**0.073**	0.074	-	-	-	-
Experimental treatment	2	0.390	-	0.654	-	0.657	-	-	-
Error		100		114		348	-	-	-

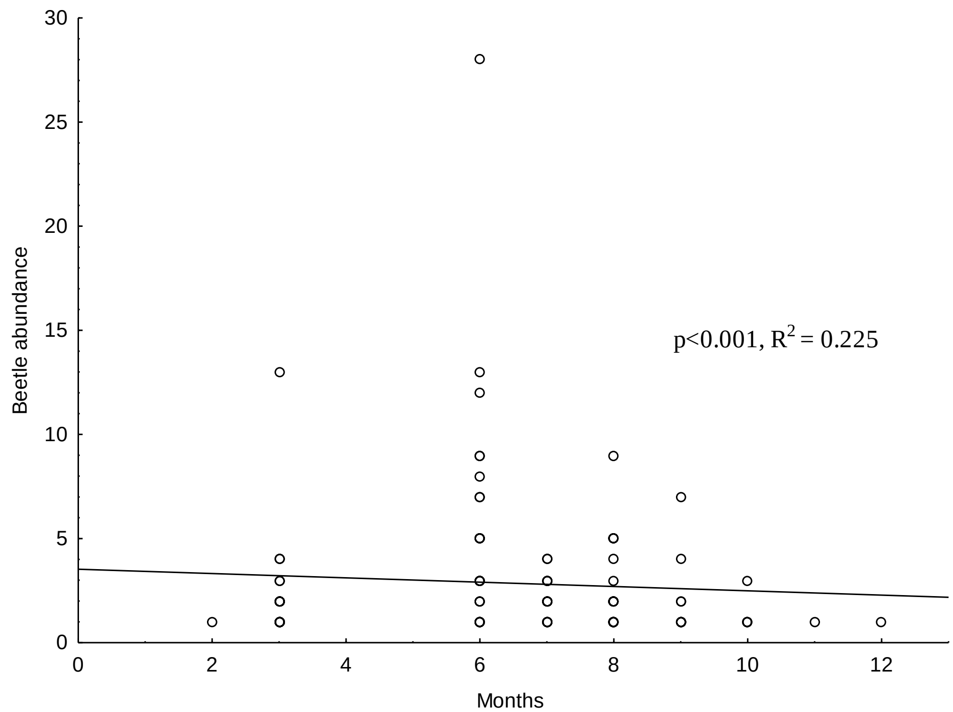

Figure 3: Monthly beetle abundance

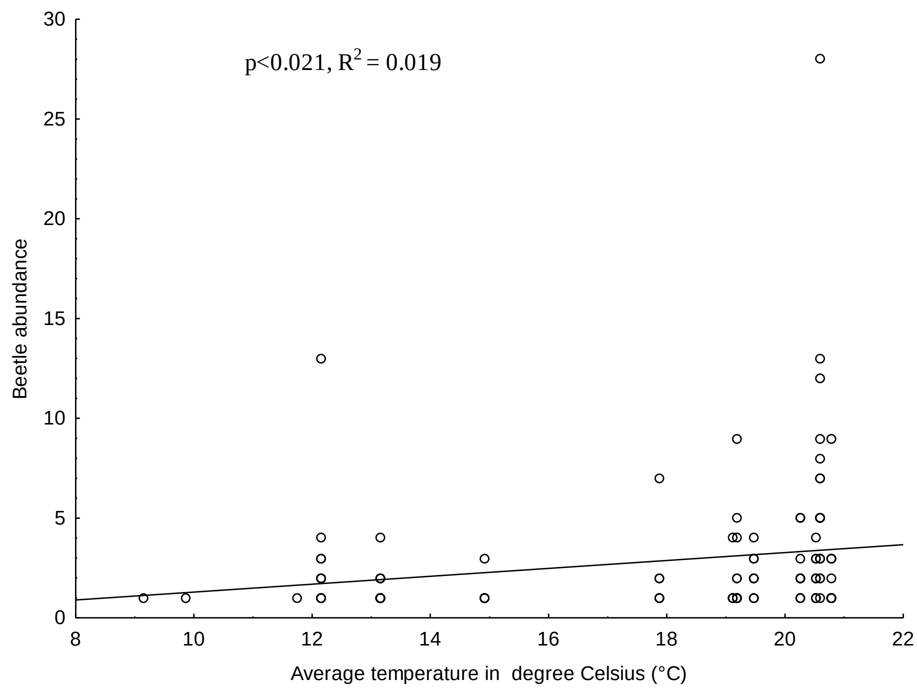

Figure 4: Beetle abundance in relation to temperature

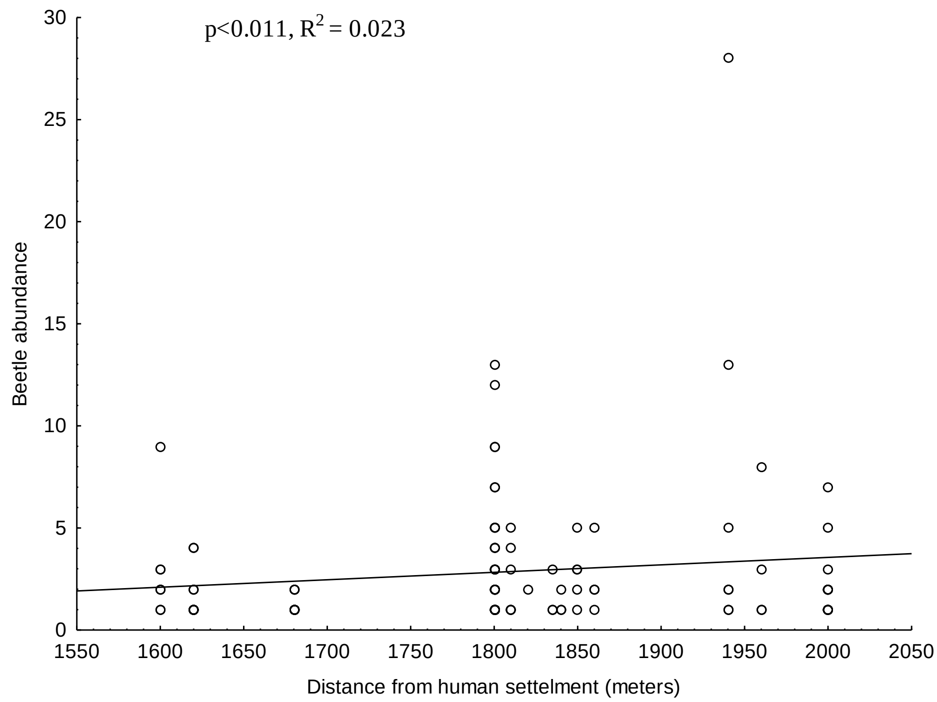

Figure 5: Beetle abundance in relation to distance from human settlement

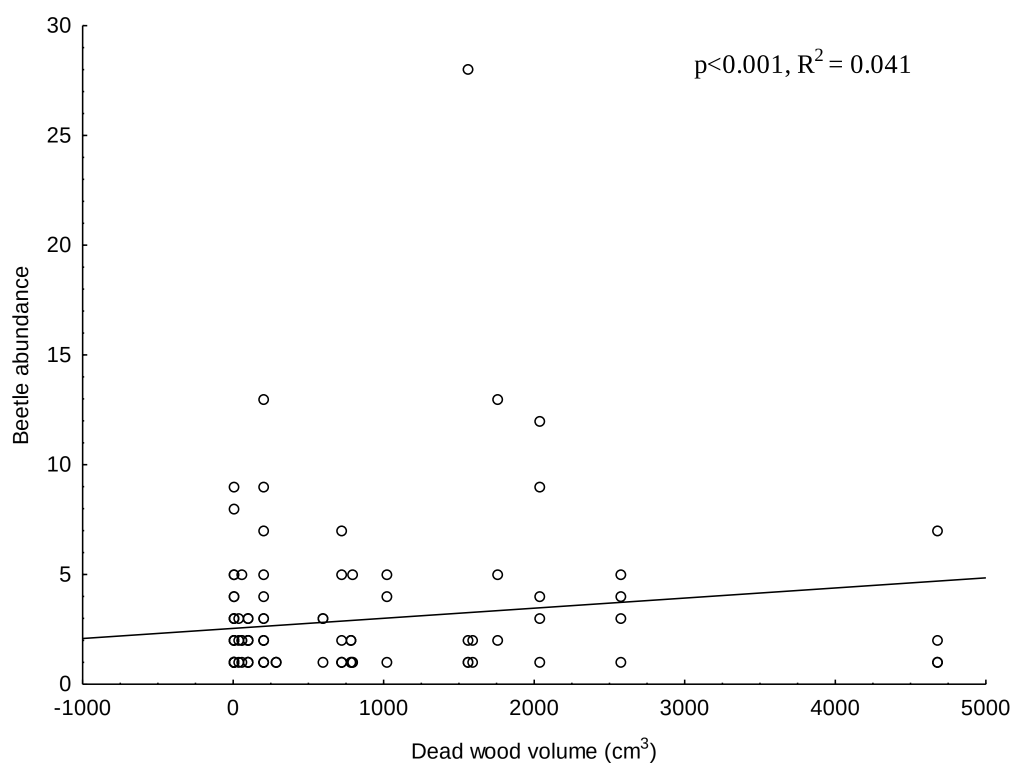

Figure 6: Beetle abundance in relation to deadwood volume

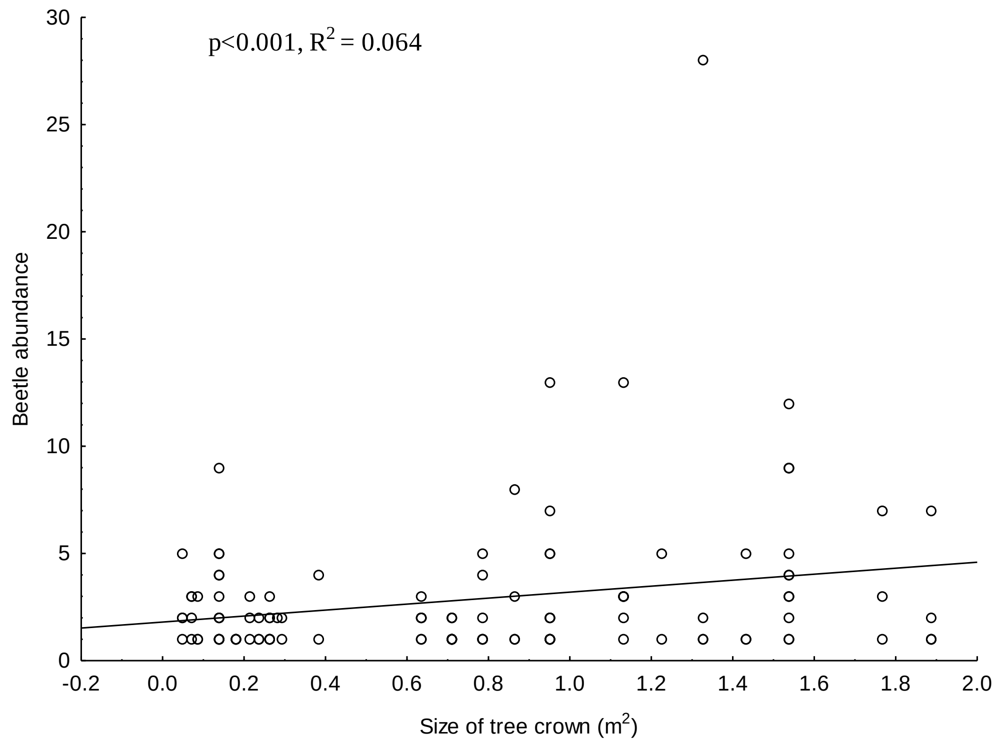

Figure 7: Beetle abundance in relation to tree canopy size

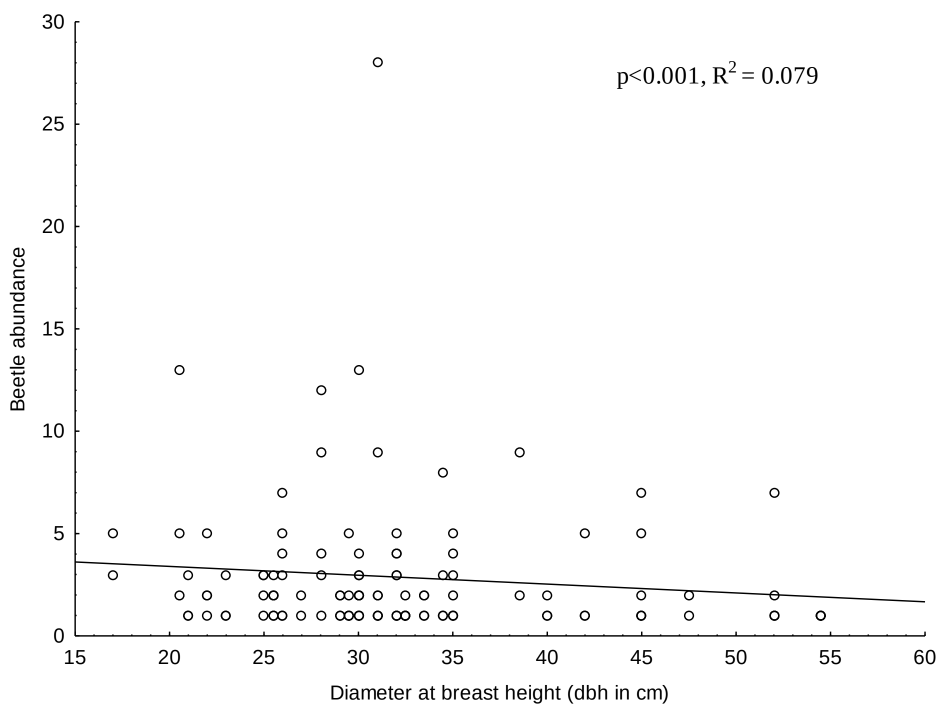

Figure 8: Beetle abundance in relation to diameter at breast height (DBH)

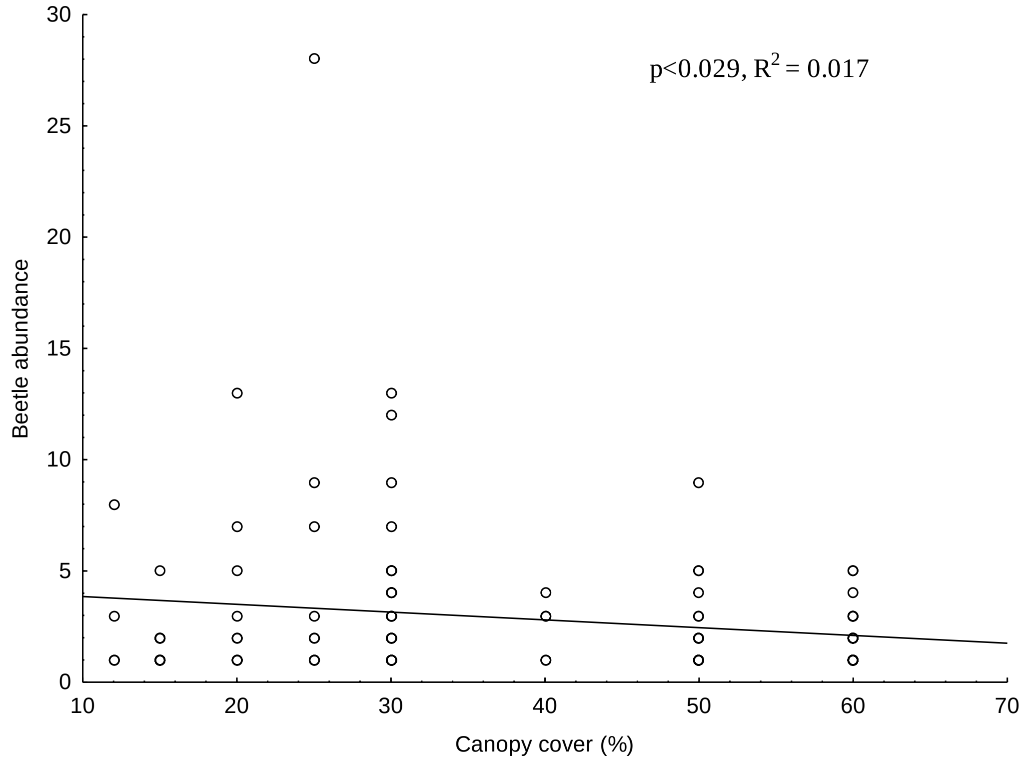

Figure 9: Beetle abundance and canopy cover

4.2 Relationship of environmental factors with species composition of different beetle

The species composition of the different beetle was affected by average monthly temperature, distance from human settlement and history of host plant (Table 1). The beetle belonging to Cerambycidae, Chrysomelidae, Attelabidae and Scarabaeidae were encountered during the time when there was higher temperature whereas beetle belonging to Coccinellidae, Curculionidae, and Erotylidae were found during the low temperatures. Beetle belonging to Cerambycidae and Chrysomelidae were with plants that were old whereas beetle from Coccinellidae and Curculionidae were in younger host plant. Likewise, beetle belonging to Endomychidae were found near human settlement whereas Attelabidae, Chrysomelidae and Scarabaeidae were found far from human settlement (Figure 10).

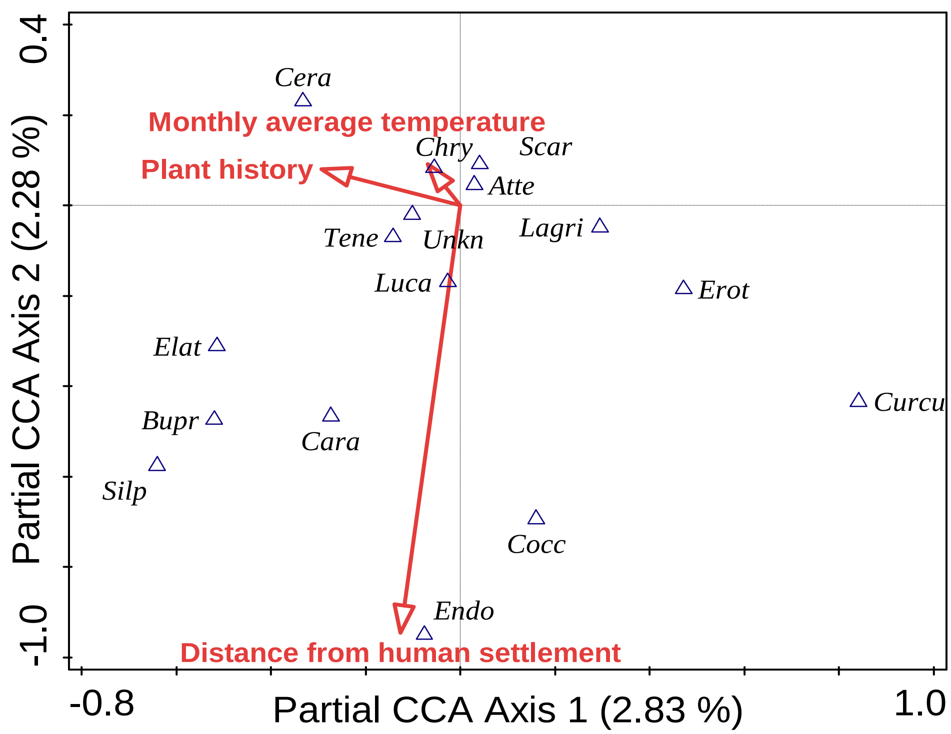

Figure 10: Results of the CCA analysis showing the effect of environmental variables on species composition of families of beetle. The first axis explained 2.83 % of total data and 2nd axis explained 2.28 % of the total data set. % explained by each canonical axis is taken as the ratio of sum of canonical Eigen value and the total of inertia obtained for CCA test.

Abbreviations: Atte-Attelabidae;Bupr-Buprestidae;Cara-Carabidae;Cera-Cerambycidae;Chry-Chrysomelidae;Cocc-Coccinellidae;Curcu-Curculionidae;Elat-Elateridae;Endo-Endomychidae;Erot-Erotylidae;Lagri-Lagridae;Luca-Lucanidae;Scar-Scarabaeidae;Silp-Silphidae;Tene-Tenebrionoidea and Unkn-Unknown**.**

Table 2: Summary of CCA analysis

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.115	0.093	0.013	0.596
Explained variation (cumulative)	2.830	5.110	5.430	20.020
Pseudo-canonical correlation	0.481	0.460	0.194	0
Explained fitted variation (cumulative)	52.06	94.01	100	0

4.3 Comparison of Coleopteran Diversity in two different study sites

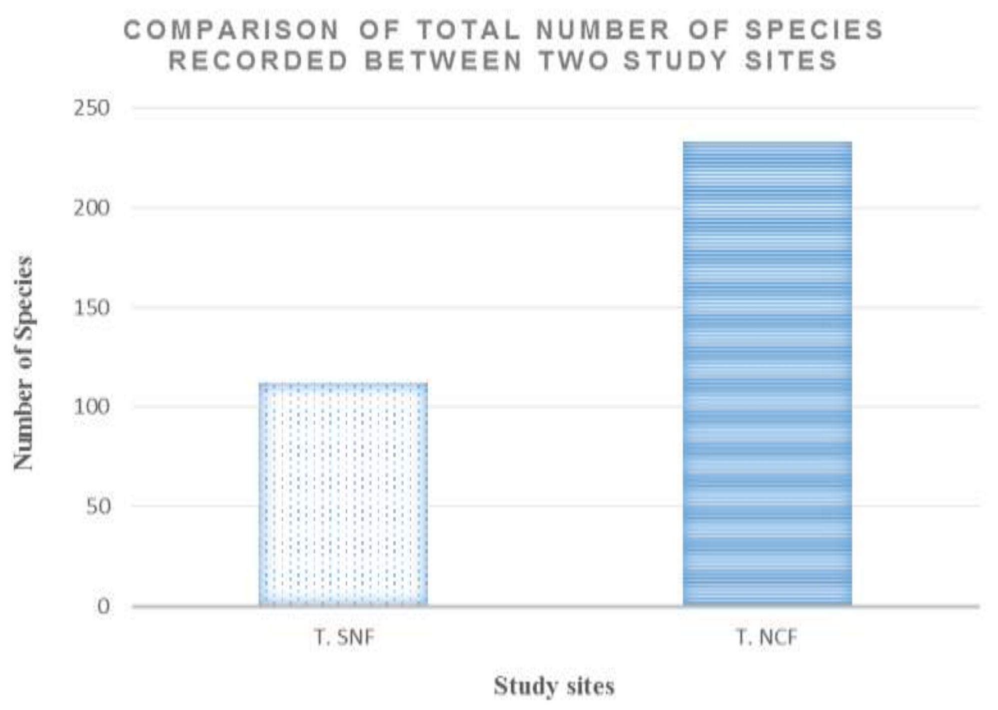

Figure 11: Comparison of Coleopteran Diversity in two different study sites

When comparing between the two studies site, Naudhara Community Forest (NCF) contributed more number of beetle (233 individuals) than Shivapuri National Park (SNP) with 112 individuals (Figure 11).

5. DISCUSSION

5.1 Diversity of canopy beetle

A survey of canopy beetle at two different forest sites (SNP and NCF) was conducted by using scientific canopy trap method. Family Scarabaeidae (171 individuals) was found highly dominant family followed by the families Buprestidae, Curculionidae and Lucanidae contributing 34, 20 and 16 individuals respectively. Ballerio and Wagner (2005) had also found similar result reporting dominance of Scarabaeidae during his study. Dung beetle (Scarabaeidae) are important in nutrient recycling, soil aeration, transport of other organism and burial of vertebrate dispersed and defecated seeds (Vulinec, 2000) and abundance of monkey population in dry forest access to availability of dung in arboreal canopy for longer duration which results to higher abundance of arboreal dung beetle in dry forest (Sabu and Nithya, 2016). Groups of monkey were frequently seen in both forests during the study period which can be one of the cause of high diversity of dung beetle in this study.

5.2 Factors affecting diversity and composition of canopy beetle in two kinds of forests

Different factors (eg. months) and environmental factors (eg. temperature, distance from settlement, dead wood volume, history of plant, size of tree crown, diameter of breast height and canopy cover) were examined with the diversity and composition of beetle. Among the environmental factors beetle abundance showed positive relation with temperature, distance from human settlement, history of plant, tree canopy size whereas negative effect was found on DBH of plant and canopy cover.

The abundance of beetle decreased with increase in canopy cover in this study. Ranius and Jansson (2000) had studied the influence of forest regrowth, original canopy cover and tree size on saproxylic beetle associated with old oaks where he concluded that abundance of beetle to decrease with increase in canopy cover which is similar to observation in this study.

The abundance of beetle increases with an increase in temperature. The activity of beetle generally increases with increased temperature (Chiverton, 1988; Luff, 1982) and their catch ability might be higher in sun-exposed trees (Ranius and Jansson, 2000). So, sun-exposed tree might have contributed to higher abundance of beetle.

The abundance of beetle increases with increase in age of host plant in this study. Beetle may prefer larger trunks because larger girth has more stable the microclimate (Ranius and Jansson 2000). Moreover, several studies also had shown that tree size (measured as circumference) was important for the species richness of beetle (Ranius and Jansson, 2000; Gough *et al.*, 2014). Large tree size also provides more stable microclimates and make easier for more fungus to establish, thus providing more habitat for fungi-associated beetle (Ranius and Jansson, 2000). In contrast, from above result (Table 1, Figure 8), the DBH of host plant has negative relation to abundance of beetle because when a hollow tree ages, trunk diameter increases along with other characteristics of the tree, for example, entrance size and volume of the hollow increase (Kelner-Pillault, 1974). Most species prefer trees of intermediate or late stages of the successional decay of living, hollow trunks (Ranius and Jansson, 2000) which is similar to findings of this study (Figure 9).

The abundance of beetle increases with increase in deadwood volume. Pilskog *et al.* (2016) had found that red-listed species richness and abundance responded to patch size, although the effect on species richness was only close to significant. This indicates that large oaks with many dead branches are especially important for the conservation of threatened species. An earlier study of red-listed beetle in hollow oaks in Norway found that species richness was positively related to circumference (patch size), proportion of oaks (low isolation), cavity decay stage, and coarse woody debris (i.e., dead wood) in the surroundings (Sverdrup-Thygeson *et al.*, 2010). They also suggested that coarse woody debris in the surroundings could compensate for small circumference and limited sun exposure. Large hollow oaks with many dead branches (i.e., large patch size) were more important for red-listed beetle species richness and abundance.

Epiphytes provide food, shelter; hunting grounds and camouflage for invertebrate fauna and their distribution depend on their specific epiphyte associations (Stubbs, 1989; Prinzing and Wirtz, 1997).There was no significant difference between environmental treatments (i.e. no impact on epiphytes, orchid removed and fern removed). This could be due to similar type of vegetation around the environmental treatments. Moreover, removal of only one type of epiphytic plant may have flourished the beetle living on another epiphytic plant species.

5.3 Comparison between Shivapuri National Park and Naudhara Community Forest

Despite the small size of the surveyed area, the study was able to reveal differences in beetle communities among the two study sites. The investigation of beetle community composition at the two study areas revealed a significantly low species overlap and thus high dissimilarity among areas. Forest management changes the spatial and temporal dynamics of dead wood (Eidmann, 1985). In managed forests, most of the suitable breeding material becomes available for bark beetle after thinning and clear-cutting, and mortality of trees is low between logging operations. It is possible that a proportion of bark beetle dispersing from their stand of origin and aggregating in stands with suitable breeding material (e.g. logging slash or occasional dying trees) is larger in the managed forest landscape than in old-growth forests, where the supply of dying trees is rather constant (Martikainen *et al.*, 1999). This kind of baiting effect, together with the apparently weaker impact of natural enemies could also explain the stronger correlation between the abundance of bark beetle and the amount of recently dead wood in managed than in old-growth stands.

The species richness is higher in managed than unmanaged forests in the first 20 years (Paillet *et al.*, 2010) and this variations could be linked to changes in forest conditions and structures (Fenton and Bergeron, 2008). The intense disturbances followed by a change in tree species composition have the strongest detrimental effect on beetle species richness (Paillet *et al*., 2010). This could be another reason for high abundance and diversity of beetle families in the community forest. Moreover, occurrence of mixed type of vegetation with flowering trees like *Rhododendron* spp. and shrubs around the sampled trees in managed forest may also have increased beetle specimens because *Rhododendron spp.* has big flower which attracts insects.

6. CONCLUSIONS AND RECOMMENDATIONS

From the present study, it was observed that Naudhara community forest supports more abundance and beetle diversity than Shivapuri National Park. Following are the main conclusions:

- Family Scarabaeidae is the dominant beetle family in Shivapuri National Park and Naudhara Community Forest.
- Managed forest contributes more to canopy beetle diversity.
- Canopy beetle are influenced by air temperature, tree canopy size, amount of deadwood available.
- Environmental treatments (no impact, orchid removed and fern removed) have no influence in canopy beetle diversity.

Based upon my study, I have recommendations for further studies and they are as follows:

- Samples should be collected twice a month to decrease the chances of specimen damage by fungus and decay.
- Dry preservation should be implicated for beetle because wet preservation of beetle in alcohol sometime results in discoloration.
- Beetle specimens should be handled carefully for photographs as mishandle may consequence into damage of specimen or body parts, specially antennas and legs.

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ANNEXES

Annexes 1: Composition of families of beetle recorded at Shivapuri National Park

Families	June	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Cerambycidae	0	5	0	0	0	0	0	0	0	0
Chrysomelidae	0	0	4	0	0	0	0	0	0	1
Elateridae	0	0	0	0	0	0	0	0	0	1
Lagridae	1	0	0	0	0	0	0	0	0	0
Lucanidae	0	1	2	0	0	0	0	0	0	0
Scarabaeidae	25	14	18	1	0	0	0	0	0	12
Unknown	1	0	12	6	0	0	0	0	0	9

Annexes 2: Composition of families of beetle recorded at Naudhara Community Forest

Families	June	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March
Attelabidae	1	0	0	0	0	0	0	0	0	0
Buprestidae	34	0	0	0	0	0	0	0	0	0
Carabidae	2	0	0	0	0	0	0	0	0	1
Cerambycidae	0	0	1	0	0	0	0	0	0	0
Chrysomelidae	3	0	0	0	0	0	0	0	0	3
Coccinellidae	2	0	2	0	0	0	0	0	0	2
Curculionidae	0	0	2	7	0	0	0	0	0	11
Elateridae	4	0	0	0	0	0	0	0	0	0
Endomychidae	0	0	0	0	0	0	0	0	0	2
Erotylidae	0	0	0	0	0	0	0	0	0	1
Lucanidae	8	1	3	1	0	0	0	0	0	0
Scarabaeidae	64	18	15	0	0	1	0	0	0	3
Silphidae	2	0	0	0	0	0	0	0	0	0
Tenebrionidae	2	0	0	0	8	0	0	0	0	0
Unknown	3	0	7	6	0	0	1	0	1	12

Annexes 3: Monthly Mean Temperature of the study sites from June 2014 to March 2015

Month	Monthly Mean Temperature of S.N.P.	Monthly Mean Temperature of N.C.F.
June	20.7831	20.59954
July	20.51913	19.46129
August	20.25345	19.17881
September	19.12245	17.86403
October	15.9013	14.92016
November	12.66042	11.74472
December	9.342608	9.149149
January	8.685887	8.557616
February	10.71349	9.854911
March	13.14694	12.15417

Annexes 4: Some photos of my research

Photo 1: Climbing to observe the trap.

Photo 2: Collecting samples from trap.

Photo 3: *Quercus* tree with code.

Photo 4: Canopy trap

Annexes 5: Some photos of recorded beetle families

Scarabaeidae

Scarabaeidae

Scarabaeidae

Scarabaeidae

Lucanidae

Lucanidae

Lucanidae

Lucanidae

Chrysomelidae

Coccinilide

Brupestidae

Elateridae