ASSESSING THE IMPACTS OF LIVESTOCK-INDUCED DISTURBANCE ON THE VEGETATION COMPOSITION & FOREST REGENERATION OF SIKKIM'S MID-ELEVATION FORESTS

Dissertation submitted to
Saurashtra University, Rajkot, Gujurat

In partial fulfillment of
Master's Degree in Wildlife Science

by Nisam Mang Luxom

Supervised by:
Dr. G. S. Rawat

Co - supervised by:
Dr. S. Tambe
Dr. S. Sathyakumar

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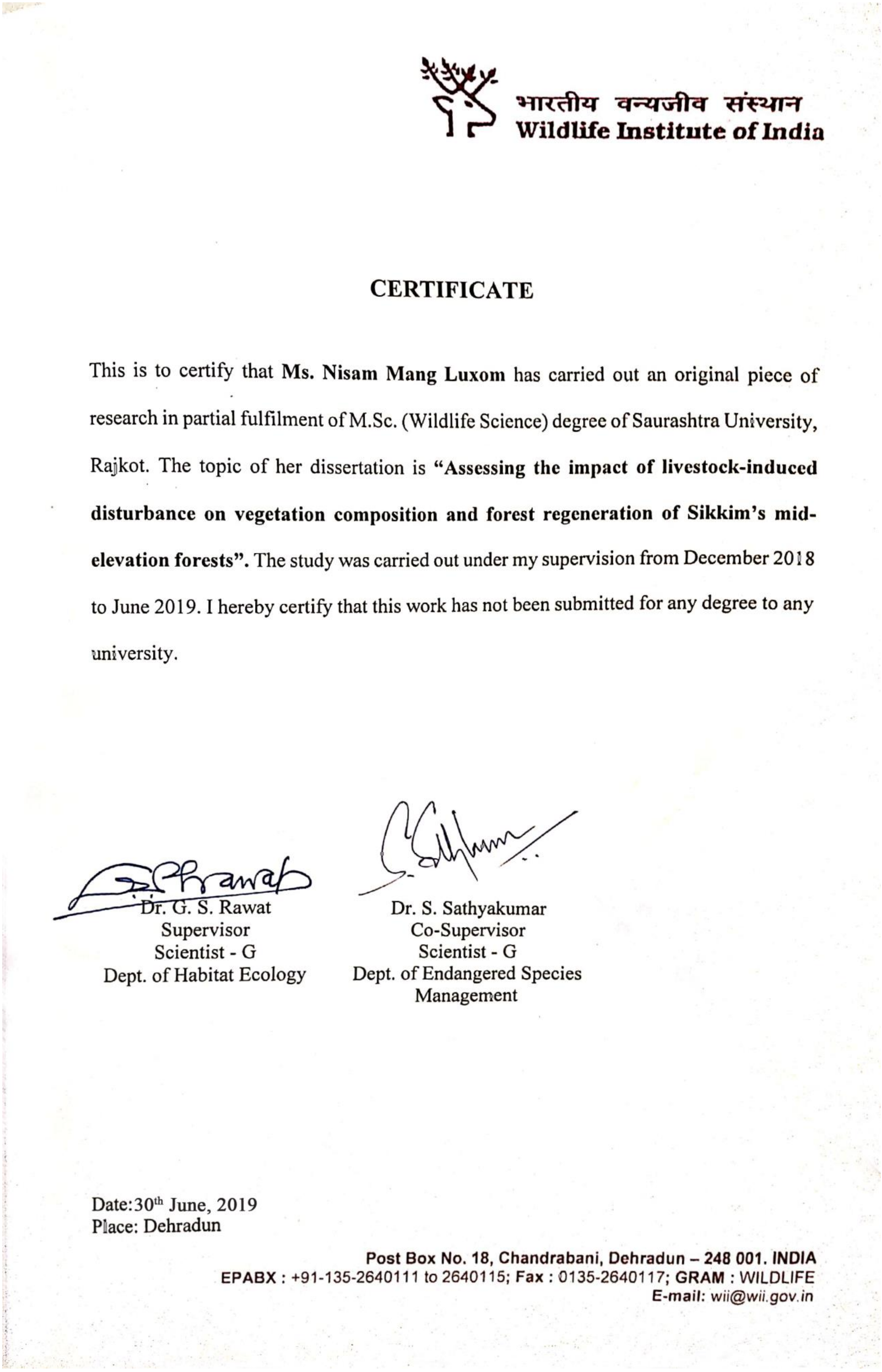
भारतीय वन्यजीव संस्थान
Wildlife Institute of India



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CERTIFICATE

This is to certify that **Ms. Nisam Mang Luxom** has carried out an original piece of research in partial fulfilment of M.Sc. (Wildlife Science) degree of Saurashtra University, Rajkot. The topic of her dissertation is **"Assessing the impact of livestock-induced disturbance on vegetation composition and forest regeneration of Sikkim's mid-elevation forests".** The study was carried out under my supervision from December 2018 to June 2019. I hereby certify that this work has not been submitted for any degree to any university.

Dr. G. S. Rawat
Supervisor
Scientist - G
Dept. of Habitat Ecology

Dr. S. Sathyakumar
Co-Supervisor
Scientist - G
Dept. of Endangered Species Management

Date: 30th June, 2019
Place: Dehradun

Post Box No. 18, Chandrabani, Dehradun – 248 001. INDIA
EPABX : +91-135-2640111 to 2640115; **Fax** : 0135-2640117; **GRAM** : WILDLIFE
E-mail: *wii@wii.gov.in*

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If I could do it all over again, I would.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

1. Livestock rearing earlier contributed sizeably to Sikkim's economy, thus putting immense pressure on natural forests, which were converted into artificial pastures. These forests have not been subjected to evolutionary grazing pressure and differ in their sensitivity to the effects of livestock grazing, as compared to the historically-grazed tropical grasslands and rangelands.
2. This study aims to assess the impacts of livestock-induced disturbance on the vegetation and forest regeneration of the Sikkim Himalayan mid-elevation forests.
3. We sampled vegetation in and around pastures under different levels of livestock grazing pressure - from currently grazed to abandoned; and from heavily grazed to lightly grazed.
4. We found highest species richness and diversity values in abandoned pastures, as compared to areas which are currently grazed as well as areas which have not had a historical pasture presence.
5. We found significant difference between plant species composition among various livestock grazing levels. Species composition differed due to (1) grazing-tolerant herbaceous species, and (2) encroaching shrub or bamboo at the pasture boundaries in the absence of livestock as a control.
6. Seedling densities were overall lower in actively grazed pastures than in abandoned pastures. Seedling densities for buffer forested areas of the different livestock grazing levels were comparable, apart from the lightly grazed treatment, which had very low seedling densities. Sapling densities was higher in and around lightly grazed pastures, than the other livestock grazing levels; this contradicts the trend seen in seedling densities.
7. Seedlings and saplings in lightly grazed areas were from the same species pool; we propose that the decrease in the former and the increase in the latter's densities is due to successful recruitment of the seedlings to the sapling stage.
8. Livestock grazing level, slope, shrub volume and position of plot (either within the pasture area or in the buffer forested area) explained seedling density. Seedling densities were highest in abandoned pastures, low in areas with high slope values, low in areas with high shrub volume and higher in buffer forested areas, compared to pastures.

9. Livestock grazing levels, slope value, shrub volume and position of sapling (wither in buffer forested areas or pasture areas) influenced sapling densities
10. Areas with and without active livestock grazing had similar proportions of unpalatable – palatable species; suggesting that direct herbivory may not be an important regulation by which density of regenerating is affected. Instead, other indirect livestock-related impacts, such as trampling or dung deposition, could lead to changes in regeneration metrics.
11. Successful regeneration occurs across the different livestock grazing levels, however the composition of regenerating species differs. Restoration of disturbed forests by artificial regeneration may not be required, as it may interfere with natural successional dynamics already in motion.

INTRODUCTION

Out of the 36 global biodiversity hotspots declared by Conservation International (Mittermeier, 2004; Myers et al., 2000; Noss, 2016), 23 are affected by livestock production practices (Steinfeld et al., 2006). Domestic livestock act as drivers of disturbance, directly through foraging and indirectly through dung deposition and trampling. Livestock grazing can affect the vegetation of natural ecosystems by influencing three components, viz., species composition, vegetation structure and ecosystem functioning (Eldridge and Bern, 2016; Fleischner, 1994). However, a survey of literature on the subject brings to light that the direction of change in vegetation, whether positive or negative, is not always definite. The relationship between livestock and vegetation of the affected area is a complicated one, with several interactions among individual species, ecosystem processes and disturbances lending to that complexity (Weisberg and Bugmann, 2003). Studies reviewing the impacts of livestock grazing at larger scales (Mazzini et al., 2018) have shown that the effects of grazing are not homogenous and depend on several localIlex dipyrenad factors, such as forest type and grazing history (Fleischner, 1994; Milchunas and Lauenroth, 1993; Onaindia et al., 2004; Vera, 2000; Weisberg and Bugmann, 2003).

Milchunas and Lauenroth (1993), based on the analysis of livestock grazing across a wide range of environments concluded that changes in species composition is a function of evolutionary history of grazing in a given area, mean annual precipitation and above ground net primary productivity. According to De Haan et al.(1997), oftentimes, the negative role that is projected onto livestock is actually a result of other pressures and distorted policies. They argue that under good management, it is possible for livestock to have a positive impact on the environment by improving soil quality and increasing biodiversity. However, such a scenario has been difficult to achieve in the recent times, due to unrelenting demand and economic expansion that leads to an increased pressure, both from the livestock and unrelated sectors, on the natural resource base.

How does livestock-induced disturbance impact vegetation?

Livestock feeding is a selective process (Awasthi et al., 2003; Luming et al., 2008; Van Soest and Soest, 1996). Due to varying sensitivities among plant species in a community towards grazing, persistent grazing could lead to alteration in species composition and eventual long-term vegetation change. Intense livestock use of a site has been shown to alter successional dynamics of the community in the long run (Uhl et al., 1988). The effects of grazing have manifested in both positive and negative changes in the vegetation of an area through selective grazing (Jeddi et al., 2010), creation of favourable or unfavourable microclimates (Sundriyal and Sharma, 1996; Vera, 2000), reduction of competition (Dorrough et al., 2004; Schütz et al., 2003; Weisberg and Bugmann, 2003), animal-mediated dispersal (Gill and Beardall, 2001; Vild et al., 2017), inherent plant traits (Allcock and Hik, 2003; Dorrough et al., 2004) and changes in soil properties (Patric and Helvey, 1986; Yates et al., 2000).

Several studies have shown that livestock-induced disturbance also affects regeneration of woody species due to direct herbivory of seedlings and saplings (López-Sánchez et al., 2014; Ruiz-Mirazo and Robles, 2012; Veblen et al., 1992; Vera, 2000) and indirectly through alteration of microclimate (Aide et al., 2000; Thadani and Ashton, 1995), soil conditions (Zimmerman et al., 2000), litter cover (Cierjacks et al., 2008), shrub cover (Bakker et al., 2004), bamboo cover (Taylor and Zisheng, 1988) and competition from understorey plants (Ehrenfeld, 1980). Other factors which influence forest regeneration are precipitation (Kakinuma et al., 2017), land use patterns (Plieninger et al., 2004; Schütz et al., 2003) and physiognomic factors (Plieninger et al., 2004).

A perusal of published literature on impacts of livestock grazing in the Himalayan forests (Awasthi, 2001; Basnet, 2006; Chettri et al., 2006; Sharma, B. K., Kulshreshtha, S., & Rahmani, 2013) reveals that there are primarily two contradicting views on the effects of grazing in the Himalayan forests: (i) that livestock grazing in the forests leads to loss of regeneration and forest degradation supporting the theory of Himalayan degradation, (ii) that moderate level of livestock grazing may lead to slight change in plant species composition and structure and such changes are not necessarily degradation. Browsing or grazing by herbivores is also known to affect successional trajectories in the forests and woodlands in several ways. Singh (1992) studied the Kumaon Himalayan system and reported wherever there is heavy livestock grazing in the banj oak (*Quercus leucotrichophora*) forests, other associated less palatable species such as *Rhododendron arboreum, Lyonia ovalifolia and Ilex dipyrena* eventually become dominant.

Through a local lens

The State of Sikkim forms a part of the Eastern Himalaya, one of the 36 biodiversity hotspots in the world (Myers et al., 2000; Noss, 2016). A large portion of the local economy used to be livestock-dependent, however, the contribution of animal husbandry and livestock development to the Net State Domestic product has reduced to 7% (Sikkim Human Development Report, 2015). Presently, households follow a diversified livelihood strategy linked to farming, livestock-rearing and tourism (Tambe, 2007).

The various extractive pressures put the natural forests in the state at risk. The state is characterized by hilly and undulating terrain with mostly forested environment. There are no natural grasslands in the state except a narrow belt of alpine zone and about 250 km^2 of Tso Lhamu Plateau representing a different biogeographic province (Rodgers and Panwar, 1988) . The natural forests of the temperate and sub-alpine zones have evolved in the absence of a strong grazing pressure (Sundriyal, 1995) . Native banpala sheep and trans-Himalayan yaks have been traditionally grazed, however cattle, Nepalese breed of yaks, yak hybrids and horses have been introduced only over the last 60 years (Tambe and Rawat, 2009a). Thus, they exhibit a different sensitivity towards the effects of grazing by introduced livestock than those systems where an evolutionary history of grazing is present.

The mid-elevation forests of Sikkim are multi-layered and have low ground fodder availability, leading livestock herders to create artificial pastures by clear felling certain areas and planting fodder grasses. These artificially created pastures are known as *kharkhas*. The most popular type of pastoral system practiced was a nomadic one. Herders would establish temporary sheds called goths in clear-felled areas. Additionally, deforestation, creation of cattle trails, lopping for fodder, collection of fuelwood and construction material also contribute to the effects of livestock-induced disturbance (Shweta Bhagwat et al., 2011; Tambe, 2007).

In 1998, the Government of Sikkim banned open grazing in reserve forests, plantations, perennial water sources. This major policy decision led to eviction of herder camps from the a lot of the aforementioned areas and saw a decline in forest grazing (Sikkim Human Development Report, 2015) . By 2002, approximately 300 pastoralists owing around 6000 livestock were evicted from the reserved forest adjacent to Khangchendzonga Biosphere Reserve (KBR) and Barsey Rhododendron Sanctuary (Tambe and Rawat, 2009b). However, due to proximity near villages and due to the presence of stray animals from yak herders on the Nepal side of the international border, some of the forested areas are still under livestock grazing. Post-ban afforestation drives have also been carried out in some sites, although not all have been successful.

Thus, there are currently four major types of livestock grazing regimes in Sikkim: (a) pristine forests that were never felled and have no livestock grazing history due to area inaccessibility or unfavourable topographical conditions; (b) abandoned pastures, which used to be grazed, but are now under strict protection and do not have current livestock presence; (c) lightly-grazed pastures, which are close to the Nepal border which is grazed by stray livestock; (d) heavily-grazed pastures, which area close to villages and are currently subjected to livestock grazing throughout the year.

By comparing vegetation composition and regeneration patterns across areas with varying livestock grazing pressures, this study aims to investigate the impacts of livestock-induced disturbance on the vegetation composition of an area and to also analyse the patterns of vegetation recovery at the sites which have been kept free from livestock grazing.

BACKGROUND AND OBJECTIVES

Problem statement

Livestock grazing is pervasive in the Himalayas, with active regulation present at very few sites. West Sikkim provides an interesting scenario where regulation has been attempted and livestock numbers have gone down. These pastoral systems in Sikkim comprising of different levels of livestock grazing intensity creates an interesting laboratory to study the impacts of livestock-induced disturbance and it's after effects. Post-ban afforestation drives have also been carried out in some abandoned sites, although not all have been successful. It is important to determine the relationship among physiognomic factors, livestock-related factors and regeneration to synthesize a meaningful forest recovery management plan. Keeping this in view, the present study was conceived.

Research questions

Objective 1: To assess the impact of livestock-induced disturbance on vegetation composition

- Q1. Does species richness and diversity vary across sites with different grazing regimes?
- Q2. Does plant composition differ across the sites with different grazing regimes?

Objective 2: To assess the impact of livestock-induced disturbance on regeneration of woody species

- Q1. How does tree seedling and sapling densities vary across the different grazing regimes?
- Q2. What is the relationship, if any, between regenerating individuals, vegetation structure and topographical variables (slope, elevation, aspect)?

STUDY AREA

Geography

The study was conducted in Western Sikkim, one of the most beautiful states of India that encompasses ca. 7100 km^2 *and located between 27° 05' to 28° 07' N latitudes and 87° 59'to 88° 56'E longitudes. The state is wedged between Nepal and Bhutan and is well-known for its scenic beauty, immensely rich biological diversity manifested by diverse*

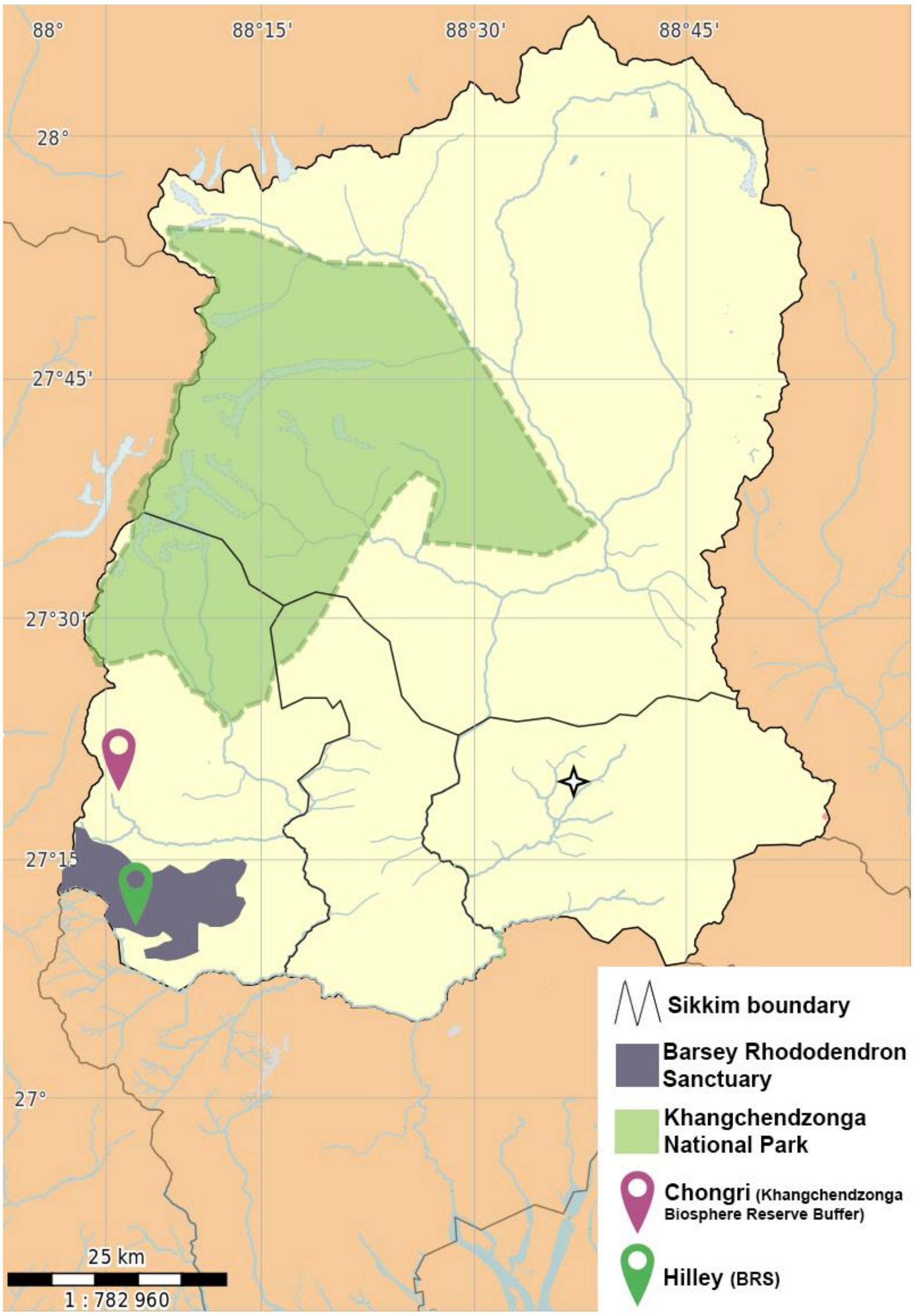

Figure 1: Map of Sikkim showing the beginning of the two herder trails (Chongri and Hilley)

eco-climatic conditions and wide altitudinal variation from about 300m to 8500 m asl (Lachungpa et al., 2003). Mount Khangchendzonga, the third highest peak in the world, and the adjacent Singalila range strongly govern the relief features on the western part of the state, while Chola range plays prominent role in determining physiography on the eastern part of the state. The landscape includes the Khangchendzonga Conservation Area in Nepal, Khangchendzonga Biosphere Reserve in Sikkim, Singalila National Park in Darjeeling Gorkha Hill Council and many other smaller protected areas in Sikkim (Fambonglo, Kyongsla, Maenam, Singba and Barsey) and Darjeeling (Senchal and Mahananda). This transboundary complex extends from eastern Nepal into Sikkim and Darjeeling of India.

Biodiversity

Sikkim serves as home for 144 species of mammals, 568 species of birds, 689 species of butterflies, 33 species of reptiles, 50 species of amphibians, 48 species of fishes, 362 species of ferns and allies, 16 species of conifers, and 5500 species of flowering plants including 38 species of rhododendrons, 11 species of oaks and 557 species of orchids (Annual Administrative Report 2015 – 2016, Government of Sikkim). The landscape provides north-south connectivity and includes relatively intact but vulnerable temperate and sub-alpine forests, especially on the Nepal side of the border. Several floral hotspots of rhododendrons, orchids and medicinal plants are also present in this complex (Lucksom, 2007; Maity and Maiti, 2007).

Study Site

Intensive sampling was conducted in West Sikkim, along two herder trails: (a) Chongri-Yambong (starting from 27°21'12.97"N, 88° 7'2.77"E) trail, which is inside a Reserve Forest located within the buffer area of Khangchendzonga Biosphere Reserve; and (b) Hilley-Jorbutey (starting from 27°11'7.51"N, 88° 7'18.73"E) trail, which is located inside Barsey Rhododendron Sanctuary. Barsey Rhododendron Sanctuary (BRS) lies in the southwest corner of the Sikkim in West Sikkim district. It was notified in 1998 and extends from 27° 09’ to 27° 16’ E latitude, and 88°01’to 88°15’ N longitude. The sanctuary spreads over 104 km^2, across the razor sharp Singalila Mountain Range, which forms the natural International border with Nepal. In the South, the Rambong Khola separates it from West Bengal. The altitude varies from 1600 m to 3600 m above mean sea level (a msl). Chongri (27° 21' 12.97"N, 88° 7' 2.77"E) is a remote village present in the buffer area of Khangchendzonga Biosphere Reserve.

Flora and fauna

The forests of the area are of the East Himalayan Moist Temperate type (Champion and Seth, 1968) dominated by *Lithocarpus pachyphylla, Quercus lamellosa, Magnolia campbellii and Acer campbelli* as overstorey trees. Major classes of vegetation in the Barsey Rhododendron Sanctuary are Moist Temperate Forest (66.81 km^2), Rhododendron Forest (29.77 km^2), Hemlock Forest (0.87 km^2), Degraded Forest (8.28 km^2) and Scrub (8.31 km^2) (Department of Forest Environment and Wildlife Management, 2008). The Sanctuary is primarily established for conservation of Rhododendron species. Of the 36 species of Rhododendron reported from Sikkim, 26 species are available in BRS. The areas with gregarious formation of Rhododendron with density more than 60% are categorized in Rhododendron forests. Rhododendron species present include *R. arboreum, R. grande, R. falconeri* and *R. griffithianum.* The understorey layer is mainly dominated by *Symplocos spp.* and *Viburnum erubescens* shrub. Pasture areas were initially deforested and thus are wide open spaces with dense grass cover. Common graminoids include *Carex* spp.*, Poa annua, Cyanodon dactylon, Luzula spicata, Juncus spp.* and *Agrostis spp* (Pradhan and Lachungpa, 2015). In abandoned and lightly-grazed sites, bamboo species present are *Yushania maling, Yushania racemose* and *Himalayacalamus falconeri.* Thorny shrub species *(Rosa sericea, Berberis spp., Rubus spp.)* have also encroached the abandoned pastures (Pradhan and Lachungpa, 2015; Tambe et al., 2005).

Faunal species in the area include leopard *(Panthera pardus),* red panda *(Aliurus fulgens),* leopard cat *(Felis bengalensis),* Himalayan palm civet *(Paguma larvata),* wild dog *(Cuon alpinus),* goral *(Nemorhaedus goral),* barking deer *(Muntiacus muntjak),* Himalayan serow *(Capricornis thar),* Asiatic black bear *(Ursus tibetanus)* and wild pig *(Sus scrofa) (WWF, 2001).* The area also showcases a high bird diversity, with a speciality of pheasants such as the satyr tragopan (*Tragopan satyra*), the Himalayan monal (*Lophophorus impejanus*) and the blood pheasant (*Ithaginis cruentus*).

Figure 2: Pasture visualisation: Grassy core, bamboo or thorny shrub at the boundary and closed-canopy forest (buffer) surrounding the pasture.

Figure 3: Yak and yak hybrids grazing in an active pasture.

METHODOLOGY

Study Design

Reconnaissance survey was carried out along the 2 catchments represented by migratory routes of herders, viz., Hilley-Jorbutey trail and Chongri-Yambong trail. Information on location of past and present camping sites of livestock, grazing areas were collated using topographic maps, remote sensing data (Forest Department 1994), social surveys and recee field visits. For each area, type of livestock grazed, number of livestock owned by different households and past and present stocking history were collated. Since, exact records of past livestock stocking rates were unavailable, pastures with similar time of abandonment and which served as both summer pastures for cattle and winter pastures for yaks were selected. All selected pastures were located in the 2300 – 3000m a.s.l. elevation band. The boundary of each pasture was digitized as a polygon using Google Earth Pro 7.3.2 and the longest line within said polygon was calculated, using ArcMap 10.5.

To also include the surrounding close-canopy forested area around the pasture, a buffer whose radius was the same as that of the longest line was constructed. We laid random sampling points 50m apart, across the pasture core and the buffer area. This also ensured proportional sampling across differently-sized pastures, as the number of random points generated within the polygon was proportional to its size.

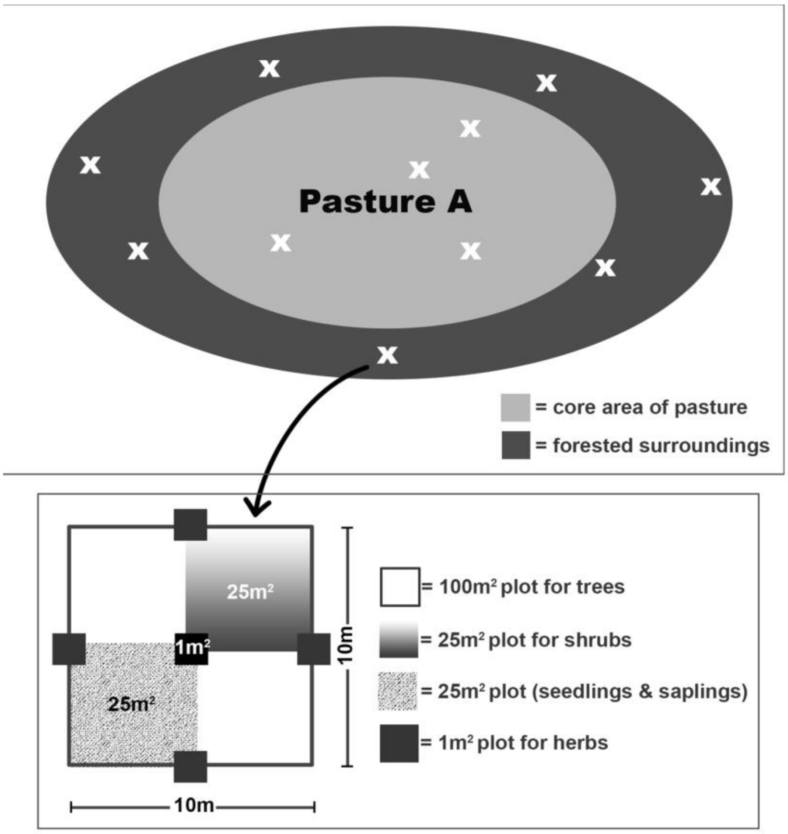

Figure 4: Study design for each pasture sampled.

Field Methods

Vegetation sampling was conducted from February, 2019 – April, 2019 across all the sites. At each site, parameters such as elevation, and geographic coordinates (latitude and longitude) were recorded using Garmin GPS Etrex 10. Plant species were identified on site using local floras (Ghosh and Mallick, 2014; Grierson and Long, 1983; Kholia, 2010; Maity and Maiti, 2007). Local experienced field guides helped in recording local names for most of the woody species which aided in remembering the unique identities. Plant species were photographed systematically preferably with flowering or fruiting twigs in order to confirm identification. If the identity of a species was uncertain, a pressed specimen was taken for identification to the herbarium at Wildlife Institute of India, Dehradun.

Objective 1: To assess the impact of livestock-induced disturbance on vegetation composition

At each sampling point within a pasture area, a 10 x 10m plot was laid following standard phytosociological protocols (Ellenberg and Mueller-Dombois, 1974). Within this $100m^2$ area, the GBH of all trees (DBH > 20cm) and poles (DBH > 10cm but < 20cm) was recorded. Number of dung/pellets of both wild and domestic animals were also noted within the $100m^2$ plot. Within 5 x 5m plots, height and circumference of shrubs were recorded. 1 x1m plots were laid at the 4 corners of the 10x10m plot as well as one at the centre of it. Within the $1m^2$ plots, herb cover (%), canopy cover (%) using a Forestry Suppliers Spherical Crown Densiometer Model A, leaf litter cover (%) and composition and bare ground (%) was recorded. In case of bamboo presence, the stem count and the height of any 2 stems randomly chosen within a 1x1m plot was recorded.

Objective 2: To assess the impact of livestock-induced disturbance on regeneration of woody species

Seedlings (height < 30cm) of different species along with their heights was recorded within a 5x5m sub-plot nested within the 10x10m plot. In the same $25m^2$ plot, the GBH of saplings (when DBH < 10cm and height > 30cm) was recorded.

Analytical methods

All statistical analyses were implemented in the R software environment (version 3.6.0; R Development Core Team, Vienna, Austria, http://www.r-project.org), using the VEGAN package for multivariate analyses (R package version 1.17-0, http://cran.r-project.org/web/packages/ vegan), the iNEXT package (R package version 2.0.6, http://cran.r-project.org/web/packages/iNEXT/) to construct to interpolate for values and ggplot2 (R package version 3.1.1., https://cran.r-project.org/web/packages/ggplot2/index.html) to assist in data visualization.

I. Species richness and diversity across grazing levels

An incidence matrix of all the plant species detected in the sampled area was constructed. Due to differences in number of plots sampled for every treatment, rarefied species richness was calculated and visualized iNEXT package in R (Hsieh et al., 2016). The species richness and diversity were calculated for the smallest sample size for a treatment (n = 29) using interpolation.

II. Species composition across grazing levels

Plots were labelled depending on their location in the core pasture area (label = “IN”) or in the buffer forested area of the pasture (label = “OUT”). Composition of woody (trees and shrub) matrix was incorporated into an abundance matrix and composition of herbaceous species was incorporated into a cover matrix. Species compositions were assembled separately for plots within and for plots outside the core area of each pasture.

ANOSIM (Analysis of similarity)

ANOSIM was used to check for significant differences between the species composition across the various grazing levels. The ANOSIM statistic compares the mean of ranked dissimilarities between groups to the mean of ranked dissimilarities within groups (Clarke, 1993). It provides an R-value which represents the dissimilarity. A high R value (close to 1) suggests dissimilarity between groups and a low R value (close to 0) suggests even distribution of high and low ranks within and between groups. We tested for significant differences separately for woody species (shrubs and trees) and for herb species (graminoids and forbs) across the different grazing levels (lightly grazed, heavily grazed, abandoned pasture, never grazed).

Non-metric multidimensional scaling (NMDS):

NMDS was performed to visualize the community ordination between the woody and herbaceous species of both IN and OUT plots, to check for any clustering that could be caused by different livestock grazing levels. Bray-Curtis dissimilarity matrix was used to plot NMDS. This method minimizes the difference, also called “stress”, between distance in the original matrix and distance in the reduced ordination space.

SIMPER (Similarity of percentages)

SIMPER analysis is a means by which contribution of each species to the observed similarity or dissimilarity between groups is measured (Clarke, 1993). The analysis uses Bray-Curtis distance and compares each sample in Group 1 to each sample in Group 2. The mean dissimilarity between two groups is thus obtained.

III. Regeneration patterns across grazing levels

Seedling and sapling densities of tree species was calculated for every plot. Seedling densities within pastures across different grazing levels and those outside pastures were tested for significant difference using Wilcoxon signed-rank test.

A Generalized Linear Model framework was used to investigate the relationship between vegetation structure, topographical variables and density of regenerating individuals. Spearman’s rank-order correlation was used to check for correlation among the covariates used for global model. The covariates tested for in the global model were grazing level, bamboo cover, shrub volume, slope, aspect and elevation. Models of best fit were built using backward selection and the model with the lowest AIC value was chosen.

RESULTS

Summary

A total of 279 plots across 8 sites were sampled (Table 1), out of which 7 were pastures and one site (Andheri Ban) had no history of livestock presence, according to social and field recee surveys conducted. The total number of species recorded across all sites for trees was 58 for trees, 17 for shrubs and 155 for herbs (Appendix 1).

Table 1: Detailed livestock stocking history of the eight sites sampled (For livestock: C = Cattle, HY = Cow-yak hybrid; YK = Yak; HO = Horse; For livestock grazing level: NG = Never grazed, FA = Fully abandoned, LG = Lightly grazed, HG = Heavily grazed)

Sl. No.	PASTURE NAME	AREA (m.sq)	PAST LIVESTOCK	CURRENT LIVESTOCK	GRAZING LEVEL	NO. OF PLOTS
1	Andheri Ban	1,56,254	None	None	NG	29
2	Dalum Bau	18,232	C, HY, YK	None	FA	50
3	Deoningalo Dhaap	54,603	C, HY, YK	HY, YK, HO	LG	64
4	Githang Chowk	27,525	C, HY, YK	C, HY, YK, HO	HG	23
5.	Lasune	5,781	C, HY, YK	None	FA	43
6.	Nayapataal	63,721	C, HY, YK	C, HY, YK, HO	HG	34
7.	Pokhri	3,835	C, HY, YK,	HY, YK, HO	LG	27
8.	Thumki	1,668	C, HY, YK	C, HY, YK, HO	HG	9

Species richness

Rarefied overall species richness was 57.207 ± 0.915 for areas with no historical and current livestock grazing (NG), 83.618 ± 0.949 for areas under heavy grazing by livestock (HG), 85.342 ± 0.915 for areas under light grazing by livestock (LG) and 97.393 ± 0.886 for pastures which have been abandoned (FA).

The various livestock grazing levels differed in number of plots sampled. For fair comparison, we chose to interpolate the species richness of each grazing level to the smallest number of plots present in a grazing level, i.e. 29 plots.

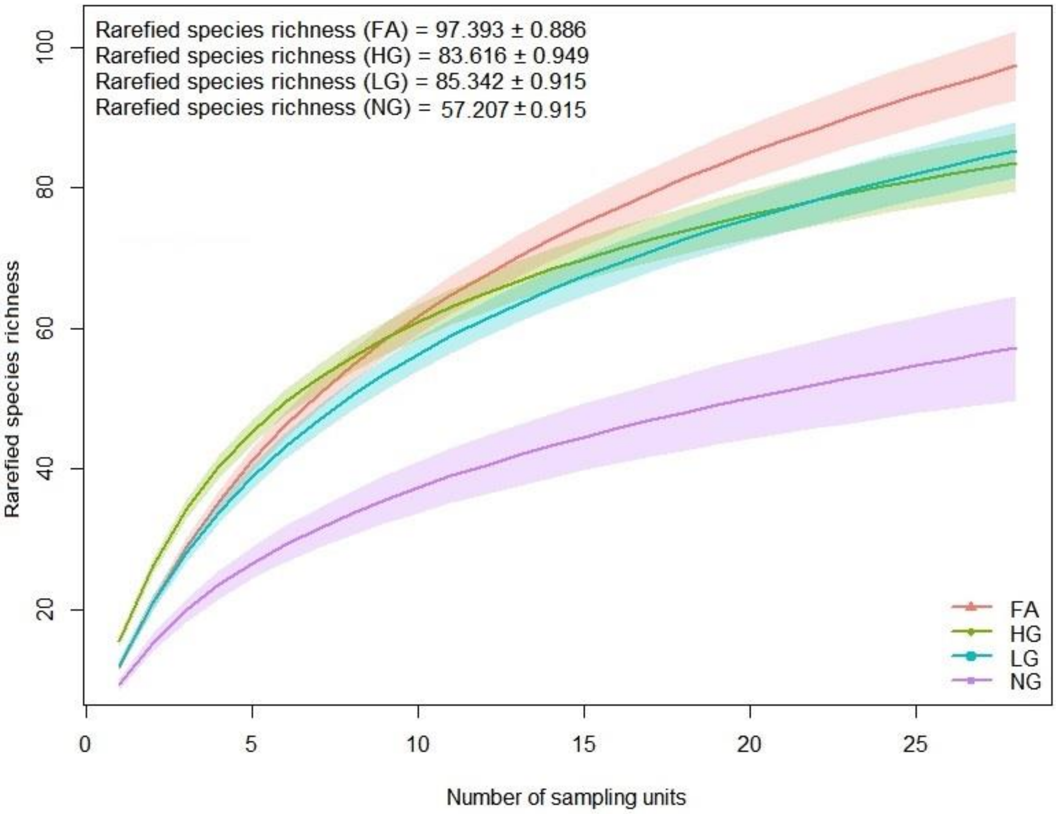

Figure 5: Rarefied species richness (n = 29) across the different grazing levels (FA = Abandoned, HG = Heavily grazed, LG = Lightly grazed, NG = Never grazed):

Species diversity

Rarefied species diversity was 34.544 ± 0.915 for areas with no past and present pasture, 67.654 ± 0.886 for abandoned pastures, 57.295 ± 0.915 for lightly grazed sites and 58.484 ± 0.949 for heavily grazed sites.

The various livestock grazing levels differed in number of plots sampled. For fair comparison, we chose to interpolate the species diversity of each grazing level to the smallest number of plots present in a grazing level, i.e. 29 plots.

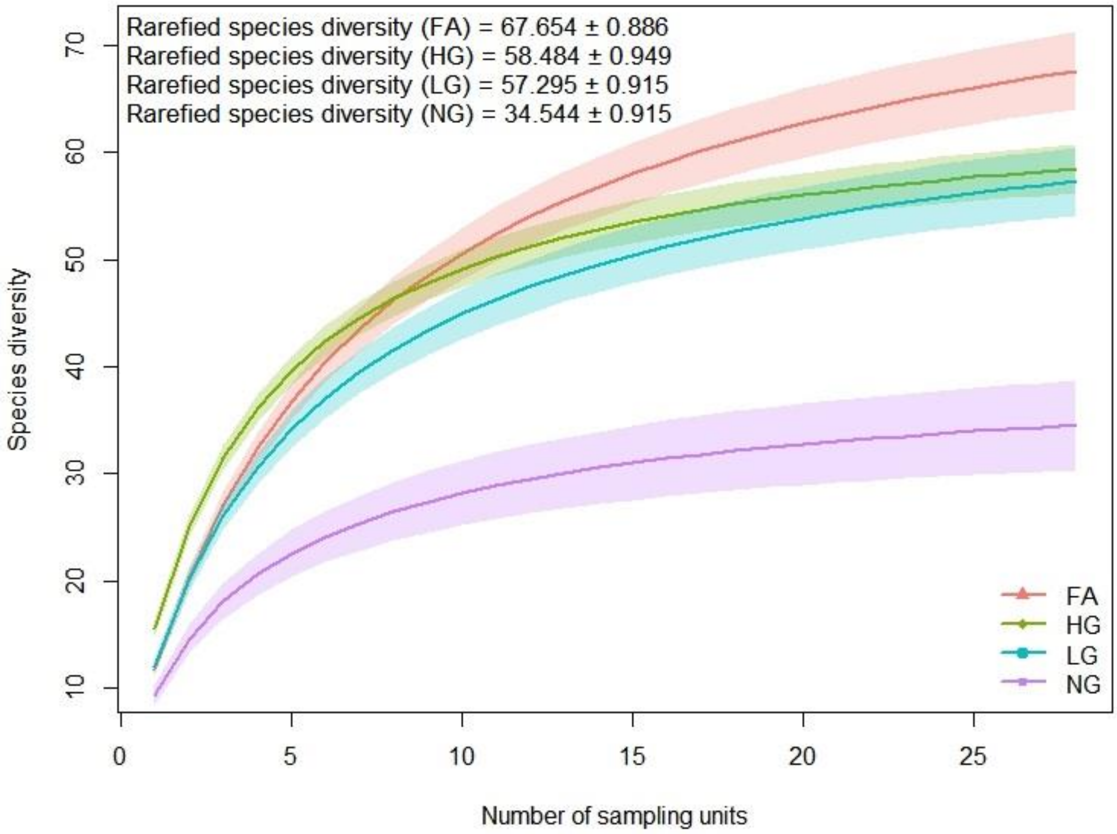

Figure 6: Rarefied species diversity (n = 29) across different grazing levels (FA = Abandoned, HG = Heavily grazed, LG = Lightly grazed, NG = Never grazed)

SPECIES COMPOSITION

We compared vegetation species composition of herb and of woody species for all combinations across different livestock grazing levels (Never grazed – Lightly grazed, Never grazed – Heavily grazed, Never grazed – Abandoned, Lightly grazed – Heavily grazed, Lightly grazed – Abandoned, Heavily grazed – Abandoned) for areas inside the pasture as well as the forested buffer areas (Appendix 2). We considered two areas to have different species composition when the ANOSIM R-statistic was > 0.4 and the p-value was < 0.005.

I. Herbaceous species composition within pasture areas

Within felled pasture areas, herb species composition was most different between lightly grazed and heavily grazed livestock grazing levels (ANOSIM R = 0.424, p = 0.001) (Figure 7).

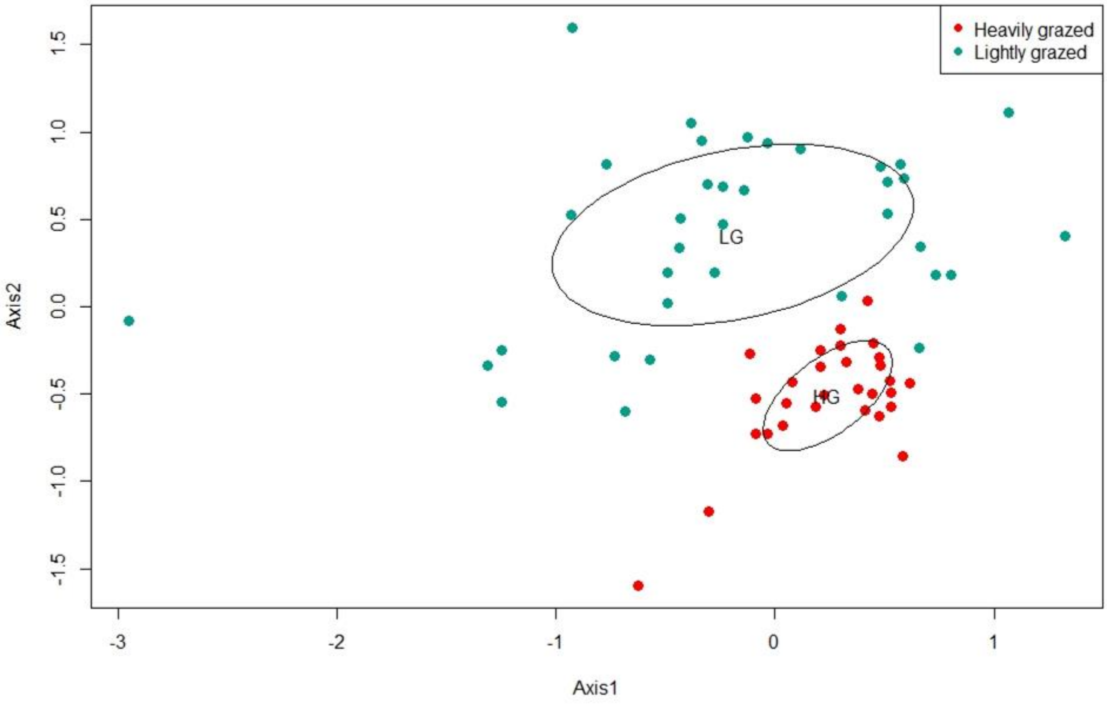

Figure 7: NMDS plot depicting difference in herb species composition in heavily grazed (red dots) and lightly grazed (blue dots) pastures.

There is higher within-group similarity for heavily-grazed pastures (red dots are closer to each other), than for lightly-grazed pastures (blue dots are spread out). According to SIMPER analysis results, the species contributing most to this dissimilarity are: *Carex longpipes (13%), Gaultheria nummularioides (10%), Cyrtococcum accrescens (7%), Carex japonica (6.2%), Pennisetum clandestinum (6%) (Appendix3).* Apart from *G. nummularoides*, these species are grazing-tolerant, fast-growing fodder species found in livestock-grazed areas.

II. Herbaceous species composition in forested buffer areas outside pastures

Herb species composition differed between the buffer forested areas surrounding lightly grazed pastures and heavily grazed pastures (ANOSIM R = 0.535, p = 0.001).

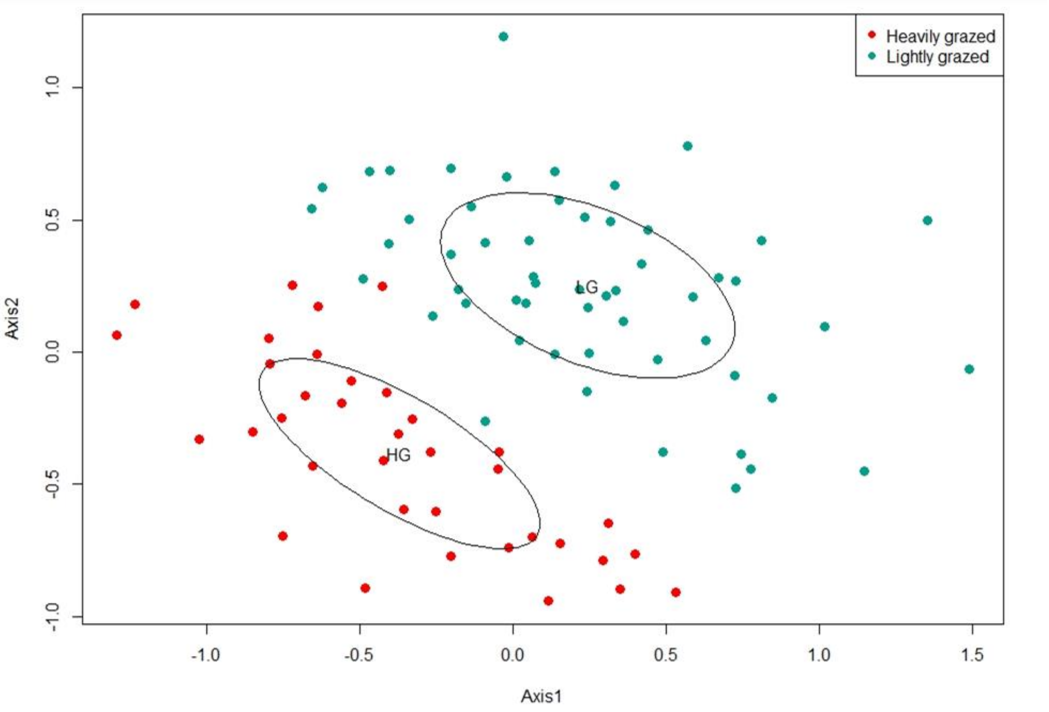

Figure 8: NMDS plot depicting difference in herb species composition in forested buffer area around lightly grazed areas (blue dots) and heavily grazed areas (red)

Within-group similarity is even for the two grazing levels (both blue and the red dots are spread out evenly). According to SIMPER results, species contributing most to the dissimilarity between herb species composition of buffer areas around lightly grazed areas and those of heavily grazed areas are *Gaultheria nummularoides* (18.40%) and *Carex duthiei* (10.39%) (Appendix 3).

The herb species within each group for different grazing levels, although different, also have a high amount of within-group dissimilarity. According to SIMPER results, the species contributing most to between-group dissimilarity are *Gaultheria nummularoides* (19.96%) and *Carex duthiei* (11.38%) (Appendix 3). *G. nummularoides* was abundant in canopy gaps and rocky areas, whereas the fast-growing, grazing-tolerant fodder species *Carex duthiei* was present in grazed pastures.

III. Woody species composition within pasture areas

Woody species composition within pastures differed between lightly- and heavily-grazed areas (ANOSIM R = 0.455, p = 0.001). The species contributing most to this dissimilarity are *Berberis hookeri* (35.56%), *Viburnum erubnescence* (27.54%) and *Rosa sericea* (24.86%) (Appendix 3).

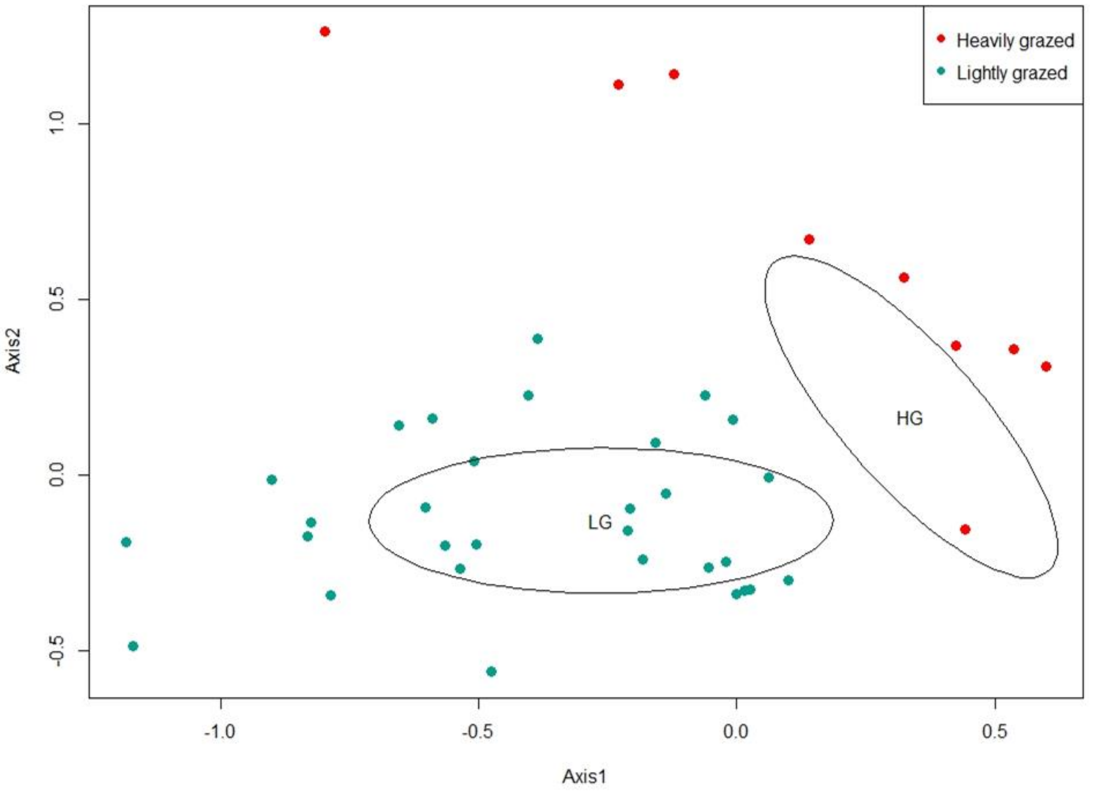

Figure 9: NMDS plot depicting difference in woody species composition in lightly grazed pastures (blue dots) and heavily grazed pastures (red)

Heavily grazed pastures had very few woody species, hence the low number of red dots in Figure 9. Lightly grazed areas had higher number of woody species, however, they were also quite dissimilar (blue dots are spread apart). Heavily grazed areas had very little understorey volume, lightly grazed areas were starting to get encroached by thorny shrubs and bamboo at the pasture boundaries.

IV. Woody species composition in forested areas around pastures

Woody species composition of forested areas surround pastures did not differ among the various livestock grazing levels; i.e. The forested areas surrounding the pastures did not differ in woody species composition.

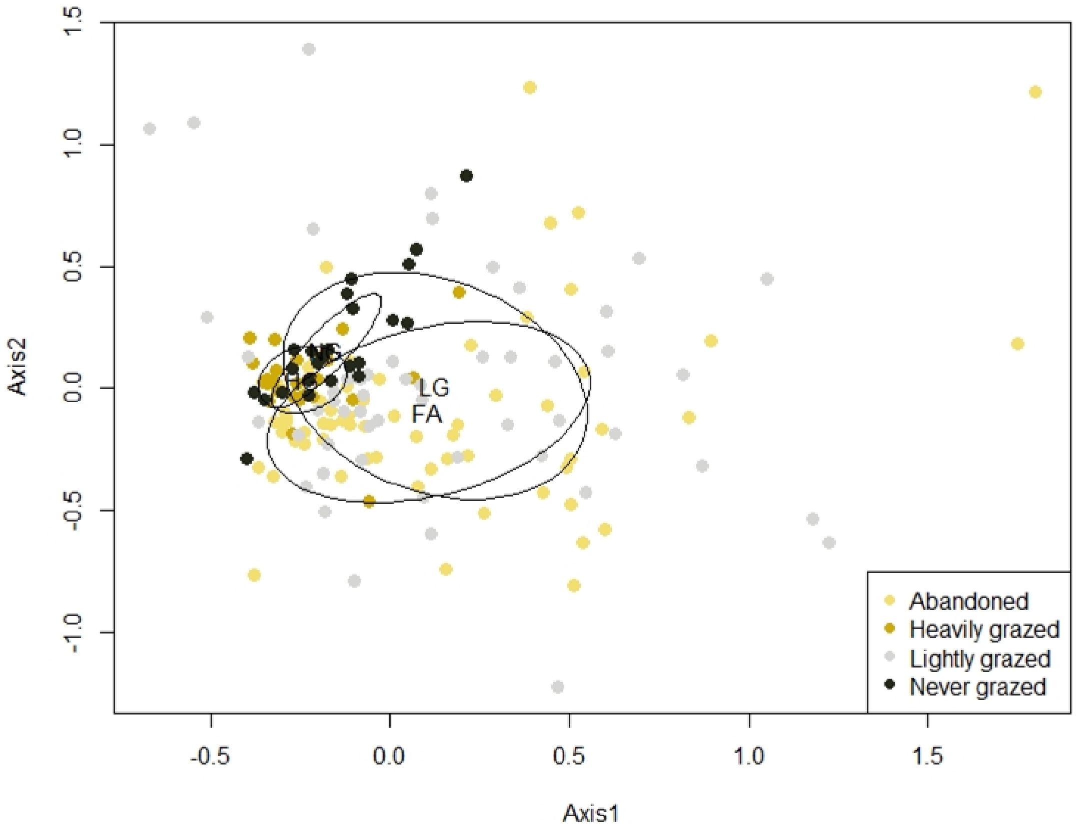

Figure 10: NMDS plot depicting overlapping species composition among areas with different livestock grazing levels

DENSITIES OF REGENERATING INDIVIDUALS

Seedling densities

Mann Whitney Wilcoxon tests revealed that seedling densities inside abandoned pastures were significantly higher than that of lightly grazed pastures (p = 1.513e-06), as well as of heavily grazed pastures (p = 5.541e-06).

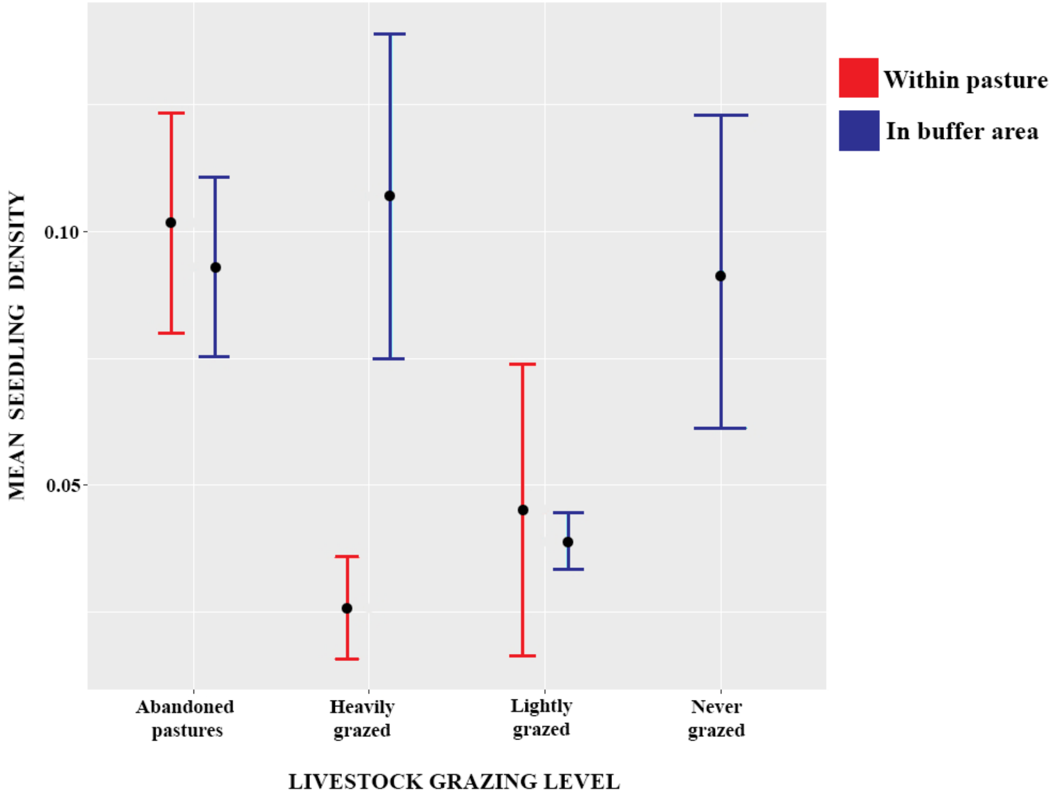

Figure 11: Mean seedling densities in both pasture (red line) and buffer areas (blue line) across different livestock grazing levels.

Seedling densities in buffer areas of lightly grazed pastures were significantly lesser than the buffer forested areas of heavily grazed pastures (p = 0.0002) and of abandoned pastures (p = 0.0005).

Seedling densities were overall lower in actively grazed pastures than in abandoned pastures. Seedling densities for buffer forested areas of the different livestock grazing levels were comparable, apart from the lightly grazed treatment, which had very low seedling densities.

Sapling densities

Mann Whitney Wilcoxon tests revealed that between sapling densities of within-pastures areas in lightly grazed sites were significantly higher than those for heavily grazed sites (p = 0.0002) as well as those of abandoned pastures (p = 0.005).

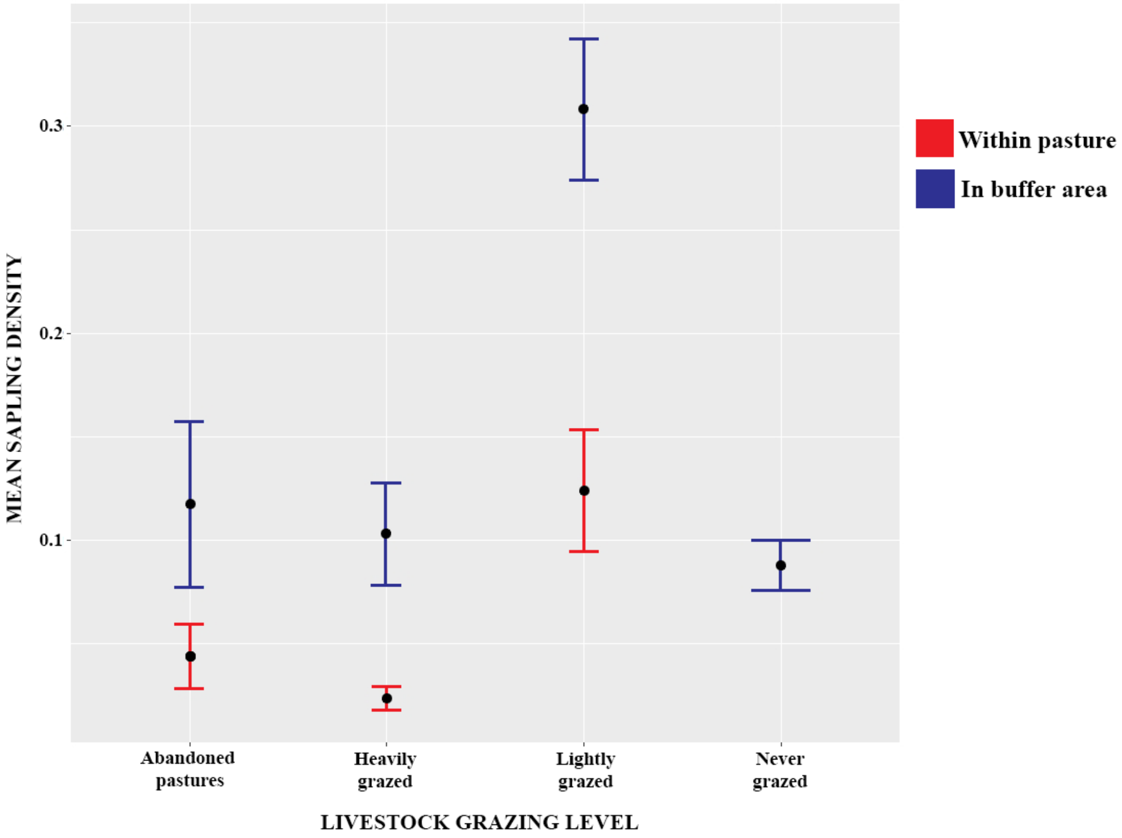

Figure 12:Mean sapling densities in both pasture (red line) and buffer areas (blue line) across different livestock grazing levels.

In the buffer areas of pastures outside the pasture core, sapling densities were significantly higher in lightly grazed pastures than in areas with no historical pasture presence (p = 2.047e-06), heavily grazed pastures (2.058e-05) and lightly grazed pastures (p = 3.181e-06).

Sapling densities was higher in and around lightly grazed pastures, than the other livestock grazing levels. The trend observed in Figure 12 contradicts the one observed in case of seedling densities (Figure 11), where lightly grazed areas had lower seedling densities. This raises the question of whether the seedling densities in lightly grazed areas are low due to their graduation into the sapling stage.

Species composition of regenerating units in lightly grazed areas

Seedling composition and sapling composition in lightly grazed areas did not differ (ANOSIM R = 0.1778, p = 0.001).

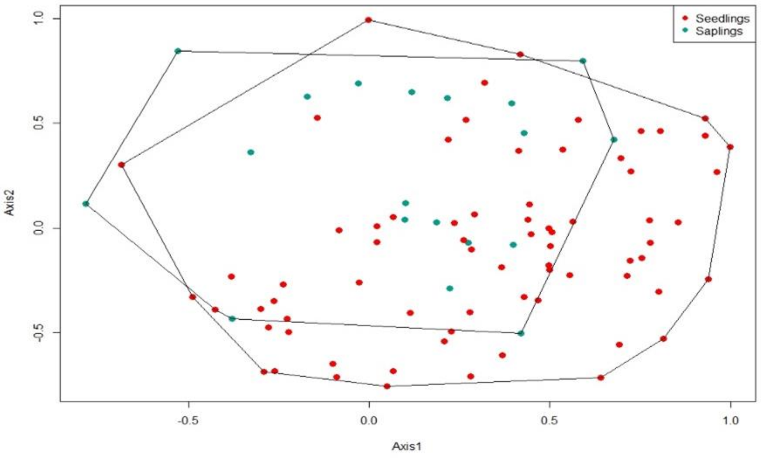

Figure 13:NMDS plot showing similar species composition for seedlings (red dots) and saplings (blue dots) in lightly grazed areas.

From Figure 13, it can be observed that the sapling species composition is a subset of the seedling species composition. This implies that only a few seedling species are able to graduate to the sapling stage.

Species composition of seedling across grazing levels

Species composition of seedlings across different grazing levels differed from one another (ANOSIM R = 0.3865, p = 0.001). SIMPER results (Appendix 4) showed that *Symplocos* sp., *Rhododendron arboreum* and *Lindera* sp. were constantly contributing towards the dissimilarities in seedling species composition across all grazing levels.

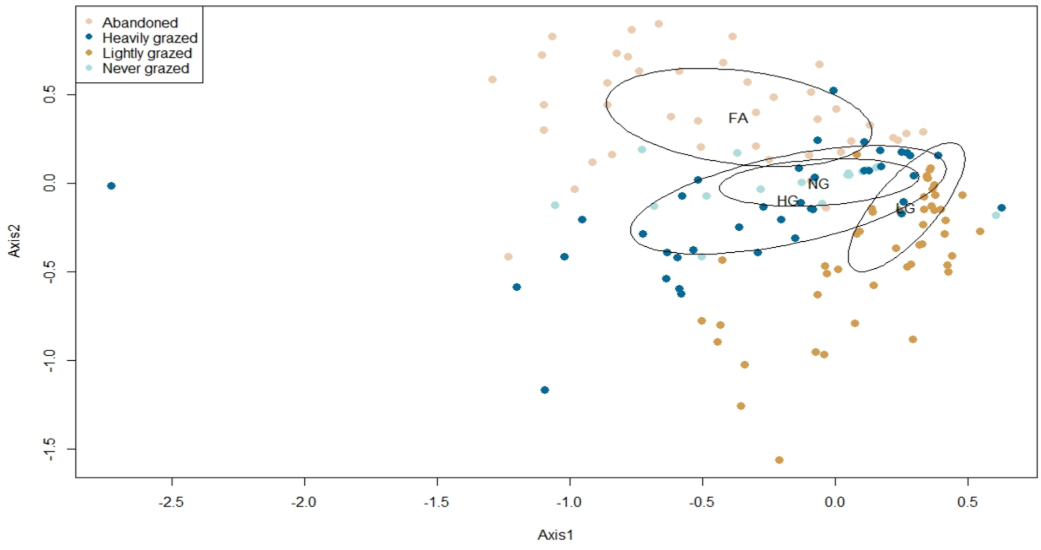

Figure 14: NMDS plots depicting seedling species composition across grazing levels

FACTORS AFFECTING DENSITY OF REGENERATING UNITS

The covariates for which seedling and sapling density was tested for were: (i) location of plot within or outside the pasture's core area; (ii) livestock grazing level (no past and present livestock grazing, light livestock grazing, heavy livestock grazing, abandoned livestock pasture); (iii) overstorey density (density of large trees with DBH >20cm); (iv) shrub volume; (v) bamboo cover; (vi) slope; (vii) aspect and (viii) elevation. We checked for correlation among the above variables using Spearman's correlation test and found weak correlation between slope and elevation (correlation coefficient "r" = -0.32, p = 0.166); as well as between shrub volume and bamboo volume (r = - 0.12, p = 0.166).

After backward selection of various permutations of the global model were run, the models with the lowest AIC values were selected.

Seedling density

According to the best-fit model (Model no. 1, Appendix 5), seedling density was best explained by livestock grazing level, slope of the area, shrub volume and location of the plot in terms of within the pasture or in the buffer forested area.

Model 1: Seedling density ~ Livestock grazing level + Slope + Shrub volume + Position

Table 2: Explanatory variables for seed density according to best fit model (Model 1).

Predictors	**Estimate**	**Std. Error**	**z-value**	**PR (> |z|)**	**Significance**
Intercept (Abandoned pasture)	2.846	0.388	7.335	2.22E-13	***
Heavily grazed	- 1.019	0.305	- 3.341	0.000833	***
Lightly grazed	- 1.605	0.298	- 5.385	7.23E-08	***
Never grazed	- 0.471	0.354	- 1.33	0.18365	
Slope	- 0.036	0.011	- 3.29	0.00100	**
Shrub volume	- 0.772	0.317	- 2.435	0.01488	*
Position: In buffer forested area	0.746	0.217	3.441	0.00058	***

Seedling density was higher in abandoned pastures (positive sign of estimate) than in actively grazed and never grazed areas. The magnitude of seedling density decrease, compared to that of abandoned pastures, was higher for actively grazed sites (with negative estimates of 1.019 and 1.605) than that of never grazed areas (negative estimate of 0.471). As seen from the negative sign on the estimates, seedling density was lesser in areas with higher slope values and shrub volume. Seedling densities was higher in buffer forested areas than within pasture areas.

Impact of direct herbivory on regeneration

We plotted proportion of seedling which are palatable to those which are not palatable to livestock. If lower seedling densities in actively grazed areas was due to direct herbivory by livestock, we would expect to see a higher proportion of palatable species in areas with no livestock presence (abandoned and never grazed areas).

We found comparable palatable - unpalatable proportion across all four livestock grazing levels. This proves that the difference in seedling densities for actively grazed pastures is not due to direct herbivory.

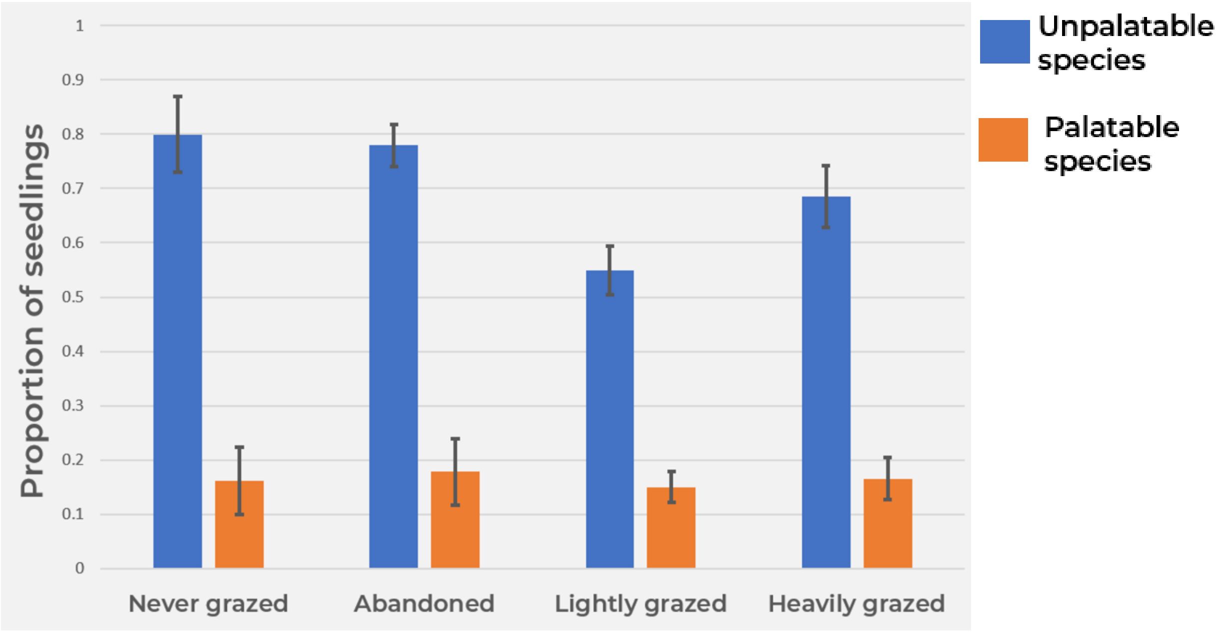

Figure 15: Proportion of palatable : unpalatable seedlings in each livestock grazing level

Sapling density

According to the best-fit models (Model no. 1 and 2, Appendix 6), sapling density was best explained by shrub volume, position of plot inside, livestock grazing level, slope and shrub volume.

Model 1: Sapling density ~ Shrub volume + Position of plot + Livestock grazing level

Model 2: Sapling density ~ Livestock grazing level + Slope + Shrub volume + Position

Table 3: Predictor variables for sapling density according to one of the best-fit models (Model 1)

Predictors	Estimate	Std. Error	z-value	PR (> |z|)	Significance
Intercept (Abandoned pasture)	1.343	0.2329	5.767	8.06E-09	***
Shrub volume	0.2063	0.1771	1.165	0.244	
Position: In buffer forested area	1.118	0.1793	6.235	4.52E-10	***
Heavily grazed	- 0.2619	0.2523	- 1.038	0.299	
Lightly grazed	0.9895	0.2203	4.491	7.09E-06	***
Never grazed	- 0.2916	0.3106	- 0.939	0.348	

Table 4: Predictor variables for sapling density according to one of the best-fit models (Model 2)

Predictors	Estimate	Std. Error	z-value	PR (> |z|)	Significance
Intercept (Abandoned pasture)	1.4691	0.3366	4.365	1.27E-05	***
Heavily grazed	- 0.3145	0.2674	- 1.176	0.2395	
Lightly grazed	0.9293	0.2552	3.641	0.0002	***
Never grazed	- 0.2888	0.3107	- 0.93	0.3526	

(continued)					
Predictors	**Estimate**	**Std. Error**	**z-value**	**PR (> |z|)**	**Significance**
Slope	- 0.0047	0.0093	- 0.505	0.6134	
Shrub volume	0.2083	0.1777	1.172	0.2412	
Position: In buffer forested area	1.1315	0.1828	6.191	5.99E-10	***

Sapling densities were higher in abandoned pastures and lightly grazed pastures (positive estimate values). Heavily grazed areas and never grazed areas had negative estimate values, implying lower sapling densities. Although not significant ($p < 0.005$), increase in shrub volume showed lesser sapling density; and increase in slope value showed lesser sapling density. Sapling densities was higher in the buffer forested area around pastures, compared to within pasture areas.

DISCUSSION

VEGETATION COMPOSITION ACROSS GRAZING INTENSITY

Abandoned pasture areas had the highest species richness and diversity, compared to any actively grazed sites or to never-grazed sites. The setting up of a livestock camp is done by initial deforestation of a forested area, which leads to openings in an otherwise dense, closed-canopy jungle. Species richness has been known to increase with management-related disturbance or formation of canopy gaps (Boch et al., 2013; Clinton et al., 1994); hence it cannot be considered to be a measure of the conservation status of the forest.

The presence of livestock in an area also leads to an increase in the number of seed dispersers (Poschlod et al., 1996). The pastoral system prevalent in our study area is a migratory one, with livestock moving seasonally from one pasture to another along elevational ranges as large as 1000m. Spore dispersal of new species by livestock would help initiate change in species composition of the affected area. This provides an opportunity for early-successional fast-growing species to colonise the area alongside the already established native species; thus, explaining higher species richness values in actively grazed areas (Pykälä, 2005; Škornik et al., 2010; Traba et al., 2003), as opposed to an area which has never been converted into pastureland through deforestation.

Prolonged livestock grazing in an area can eventually lead to homogenisation of the targeted area’s species composition, leading to a dominating presence of grazing-resistant species (McEvoy et al., 2006). Our results differ from previous studies where pasture abandonment has led to a decrease in species richness (Pykälä, 2005). With pasture abandonment, the grazing-sensitive species, which would have otherwise been unfit for survival, are able to proliferate and this manifests as an increase in species richness for abandoned pastures. Previous long-term studies conducted in abandoned systems suggest that species richness of abandoned arable or pasture land increases initially but with eventual succession and canopy closure, the species richness starts to decrease (Harmer et al., 2001; Smit and Olff, 1998).

From species richness and diversity patterns in our study, it is clear that the species diversity parameters of pastures that were abandoned around 15 years ago are still quite varied from the supposed “control” area of sites which have not been exposed to livestock grazing; and thus will take a long time for full transition from open, grassy pastureland to closed-canopy climax forest.

FACTORS AFFECTING REGENERATION OF WOODY SPECIES

Effect of livestock-induced disturbance on regenerating individuals

Seedling densities were significantly lower in actively grazed sites, compared to abandoned and never grazed pastures (Figure 11). Seeding densities have been reported to be negatively impacted due to direct herbivory (López-Sánchez et al., 2014; Ruiz-Mirazo and Robles, 2012; Shimoda et al., 1994; Veblen et al., 1992). Lightly grazed areas should a progression in age class of seedlings to saplings. We checked whether palatability or unpalatability of a species played a role in it's regeneration niche in our area. However, the results (Figure 15) proved that palatability of a species did not affect seedling densities in case of lightly-grazed areas. The main livestock-related factor, other than direct herbivory, which has been known to impact regeneration of seedlings is trampling. Trampling results in changes to soil properties and soil compaction (Aide et al., 2000; Eissenstat and Mitchell, 1982; Uresk and Boldt, 1986) which could hinder regeneration growth.

Sapling density was higher in lightly grazed areas (Figure 12). This appears to be an advantage for growing saplings present in said area as: (1) once they graduate from the seedling stage, saplings are able to better handle grazing pressure from livestock through morphological changes (Zida et al., 2007) and their survival is more probable; and (2) they are not suppressed under the relatively dense canopy cover present in the never-grazed pastures (Palmer et al., 2004).

Effect of topographical variables on regenerating individuals

Seedling and sapling densities were lower in areas with higher slope values. This may be due to differences in soil stability and drainage with change in slope value of an area. Steeper slopes have less water retention capacities. They also have less soil to facilitate soil binding and seedling-sapling establishment, thus leading to lower seedling and sapling numbers in such areas.

Effect of vegetation structure on regenerating individuals

The impact of understorey structure on regeneration has been well-studied. Shrubs often act as safe sites for saplings and seedlings by providing microclimate amelioration, protection from browsing, and enhancing soil fertility (Gómez-Aparicio et al., 2005; Jensen et al., 2012; Raffaele and Veblen, 1998; Van Uytvanck et al., 2008). However, the negative effect of shrubs on regenerating units, through the same processes that act as safe sites, as the has also been documented (Clinton et al., 1994; Lambers and Clark, 2003).

The strength of shrub facilitation also depends on how grazing-sensitive the nursed species are, as well as whether the shrub species itself is a target of browsing or grazing, in which case seedling growth could be affected due to incidence browsing . In our case, seedling density was lower in areas with high shrub volume (Table 2). The shrubs present in the study area achieved tall heights (> 2m) and had wide circumferences. This could negatively impact seedlings due to: (1) impediment of the physical space dimension of their regeneration niche (Grubb, 1977); and (2) canopy closure due to bulk of the shrub's vegetation (Puerta-Pinero et al., 2007). Shrubs have also been shown to alter soil properties, especially temperature (Gómez-Aparicio et al., 2005; Myers-Smith and Hik, 2013), which can in turn affect growth rates and resilience of woody seedlings (Larson, 1970; Teskey and Hinckley, 1981).

CONCLUSION

Our results indicate that livestock-induced disturbance had an impact on the vegetation composition and forest regeneration of an area. Vegetation composition among grazing levels differed due to differences in (1) grazing-tolerant herbaceous species, and (2) encroaching shrub or bamboo at the pasture boundaries in the absence of livestock as a control.

Successful regeneration occurs across the different livestock grazing levels, however the composition of regenerating species differs across grazing levels, with canopy-gap species such as *Symplocos* sp., *Rhododendron arboreum* and *Lindera* sp. constantly contributing to dissimilarity across all grazing levels. Restoration of disturbed forested by artificial regeneration may not be required as it may interfere with natural regeneration and dis-balance the successional dynamics already in motion.

Factors affecting regeneration included livestock grazing level, slope, shrub volume and position of plot within or outside a pasture. In case of lightly grazed areas, seedlings were being successfully recruited into saplings. Surprisingly, palatability of a species proved to be less important in it’s regeneration cycle, than other studies have proved. Other factors such as trampling by livestock, it’s resulting soil composition and texture changes seem to play a bigger role in regeneration success in this area.

WAY FORWARD

The ban on open grazing by the Sikkim government has on one hand led to improvement in standing stock, enhanced biodiversity and aided in restoration of wildlife habitat (Bhagwat et al., 2011; Department of Forest Environment and Wildlife Management, 2016). On the other hand, however, it has resulted in a loss of traditional livelihood for a large number of households and adversely impacted the socio-economic security of the herders dependent on livestock rearing as their livelihood (Sikkim Human Development Report 2014, 2015).

Due to intensification of livestock production, limited fodder and stationary dung deposition, seasonal grazing in this landscape has been proven to have negative impacts on the Sikkim ecosystem. Appropriate incentives should be provided to the agro-pastoral communities for good conservation practices and alternate livelihood options for households dependent solely on livestock needs to be facilitated by the forest authorities. The shift in livelihoods from a solely migratory pastoral system towards integrated agriculture- and tourism-related sectors, has led to an all-round development and growth of the community. Stall-fed cattle at lower elevations (< 2000m) may be used as supply for the state's growing milk industry. The milk industry can further strengthen it's market pull by expanding its network of milk cooperative soceities, breed improvement initiatives and setting up milk chilling plants in remote villages.

The mid-elevation forests, previously used for pasture creation, should be protected to reap non-consumptive benefits such as improved spring water quality, growth of trekking tourism and disaster risk reduction. A plan for long-term monitoring of abandoned pastures should be written up to ensure that the abandoned pastures stay abandoned and that natural restoration is able to occur.

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APPENDIX 1: *List of plant species sampled during study*

Botanical names	Local Name
Abies densa Griff.	Gobre Salla
Acer campbellii Hiern.	Kapase'
Acer hookerii Miq.	Kapasi
Acer sterculiaceum Wall.	Thulo Kapase
Aconitum bisma (Ham.) Rapaicus	Bikh
Aconogonum molle (D. Don) Hara	Thotne
Aconogonum sp.	Rani Thotne
Agapetes hookeri (Cl.) Sleum	Rukh Gurans
Agapetes serpens (Wt.) Sleum	Rukh Gurans 2
Ailanthus sp.	Khanak pa
Agrimonia pilosa	UnID JTN
Agrostis micrantha Steud.	Gaughas1
Agrostis pilosula Trin.	SBS
Ainslaea latifolia (D. Don) Sch.-Bip.	UnID A/A; THM
Anaphalis adnata (Wall. Ex DC.)	UnID LBK
Anaphalis busua (Buch.-Ham. Ex D. Don) DC.	Thulo bukki
Anaphalis royleanus DC.	Syano Bukki
Anaphalis triplinervis (Sims.) Cl.	Bukki phul
Arachnoidea coniifolia (Moore) Ching	Unew
Araiostegia beddomei (Hope) Ching	Unew2
Arenaria debilis Hk. F. Ex Edgew.	TLA
Arisaema griffithii Schott	UnID CBS
Arisaema nepenthoides (Wall.) Mart. Ex Schott	UN
Artemisia vulgaris L.	Tite pati
Begonia parviflora Hara	UN
Berberis insignis Hk.f.&T.	Chuthro
Berberis hookeri Lem.	Khas Chutro
Berberis sp.	Dabai Chutro
Berberis sp.2	Chutro
Betula alnoides D. Don	Saur;
Betula utilis D. Don	Bhujpat
Bidens pilosa L.	Dumse Kudo
Botrychium sp.	SFC
Brassaiopsis hispida Seem	Phutta
Brassaiopsis sp. (?)	Ban Kera
Bulbophyllum reptans Lindl.	Orchid
Calamogrostis emodensis Grisebach.	Syal Puchhare'
Cardamine flexuosa With.	Saili Saag
Cardiocrinum giganteum (Wall.) Makino	UN
Carex capillacea Boot	THD
Carex cruciata Wahlenb.	Harkat
Carex duthiei Cl.	MHKT

Carex filicina Nees	TBD
Carex japonica Thunb	HHK
Carex longipes D. Don	UnID MHK(1)
Cerastium sp.	Avizal
Chaerophyllum reflexum Aitch.	UnID DTH
Chamabania cuspidata Wight.	Bhui Chiple
Chlorophytum nepalense (Lindl.) Baker	UN
Choerospondias axillaris (Roxb.) Burtt. & Hill	Lopsi
Cirsium verutum (D. Don) Spring.	Ghore kada
Clematis smilacifolia Wall.	UnID RDN; ROD
Coniogramme intermedia Herion.	Unew4
Coniogramme procera Fee	Unew5
Coniogramme pubescens Hieron.	Bamboo basket fern
Coniogramme serrulata (Blume) Fee	Tite Unew
Coriaria nepalensis Wall.	Junpe
Cotoneaster microphyllus Wall. ex Lindl.	Khareto
Crassocephalum crepidioides (Benth.) Moore	Kacho Pate
Crawfurdia speciosa Wall.	UnID HSS
Cryptomeria japonica (Thunb. Ex L.f) D. Don	Dhupi
Cupressus corneyana Carr.	Deodar
Cyathula capitata Moq.	Musae kudo
Cynodon dactylon (L.) Pers.	Pennisetum clandestinum
Cynoglossum wallichii G. Don	UnID MLA
Cynoglossum sp.	Dhedu Kudo
Cyrtococcum accrescens (Trin.) Stapf.	Cyrtococcum accrescens
Daphne bholua Buch.-Ham. Ex D. Don	Pateli Argaili
Daphne retusa Hemsl.	Lokta
Dennstaedtia appendiculata (Wall. Ex HK.) Sm	Unew6
Deparia boryana (Willd) Kato	UN
Dichroa febrifuga Lour.	SBJ; Barkey Kibu
Digitaria sp.	Gau Jhaar
Diplazium stoliczkae Bedd.	Tite Nigro
Dipsacus inermis Wall.	Mulpaate'
Dodecadenia grandiflora Nees	Guey Pahele
Drepanostachyum intermedium (Munro) Keng f.	Tite nigalo
Dryopsis apiciflora (Wall. Ex Mett.) Holt. & Edw.	UnID DTU; CTU
Dryopteris wallichiana	Bako Mirmire
Dryopteris sp.	WVW; SPU
Edgeworthia gardneri (Wall.) Meisn.	Argail
Elaeagnus conferta Roxb.	UN
Elatostemma monandrum (D. Don) Hara	Gogleto
Elatostemma obtusum Wed.	Syano gogleto
Elsholtzia fruticosa D. Don	Gurpis
Elsholtzia strobilifera Benth.	Phurmang
Elsholtzia flava Benth.	Bhatmase'
Epilobium wallichianum Haussk.	SSH

Erigeron sp.	Lise kudo
Eriocaulon sp.	Naram Harkat
Euonymus sp.2	Jinguna; Chari Lise
Eupatorium adenophorum Spreng.	Ban Maara
Euphorbia sikkimensis Boiss	Chattu
Eurya acuminata DC.	Jinguna
Ficus neriifolia Sm.	Dudhilo
Fragaria nubicola Lindl. Ex Lac.	Bhui Aisalu
Galium asperifolium Wall.	Lek Majito
Galium elegans Roxb. Var(?)	UnID OPF
Gaultheria fragrantissima Wall.	Khekia
Gaultheria nummularioides D. Don	UN
Gentiana capitata Buch.-Ham. ex D. Don	Chaar kone; Pangen metok
Geranium donianum Sw.	Taane' Jhar
Geranium polyanthes Edgew.	Taane' phul
Gerbera piloselloides (L.) Cass.	Aalu Pate
Geum elatum Wall. Ex G. Don	Belochan
Girardinia diversifolia (Link.) Friis	Bhangde Shishnu
Gleichenia sp.	Monale'
Gynura nepalensis DC.	UN
Hedera nepalensis K. Koch.	Dude' Lahara
Hemiphragma heterophyllum Wall.	Aakhalein
Himalayacalamus falconeri (Munro) Keng f.	Singhane
Himalayacalamus hookerianus (Munro) Stap.	Parang
Holboelia latifolia Wall.	Gulpha
Houttuynia cordata Thunb.	Raat Leulo
Hydrangea heteromalla D. Don	UnID CLH
Hymenophyllum exsertum Wall. Ex Hk.	UN
Hypericum hookerianum Wt.	UnID CLS
Ilex crenata Thunb.	Seti Kaath
Ilex dipyrena Wall.	Lise
Ilex hookeri King	Lissi
Ilex sp.	WHS; Bhui Chirchimira
Impatiens decipiens Hk. f.	UnID RWK
Jasminum dispermum Wall.	Phalame Lahara
Juncus chrysocarpus Buch.	SNG
Juncus himalensis Klotzch.	UN
Juncus inflexus L.	Juncus 2
Juncus leucanthus Royle ex D. Don	UN
Juncus thomsonii Buchen.	Phurke' Buki
Ligularia mortonii (Cl.) Hand.-Mazz.	Bikh jhar
Lindera elongata (Nees) Hk.	Karchula; UnID GPH
Lindera pulcherrima (Nees) Kh.f.	Si-Si
Lindernia sp. (?)	Pahele
Lithocarpus elegans (Bl.) Soep.	Arkaula
Lithocarpus pachyphyllus (Kurz.)Rehder	Sungre Katus

Lonicera acuminata Wall.	WHT
Luzula spicata L.	Thulo Cyrtococcum accrescens
Lycopodium japonicum Thunb.	Nagbeli
Lycopodiella cernua (L.) Pichi - Serm.	Syano Nagbeli
Lyonia ovalifolia (Wall.) Drude	Angeri
Lysimachia sp.	Piure'
Machilus duthiei King ex Hk.f.	Ghiu Kaulo
Maesa chisia Don	Jat Kharane
Magnolia campbellii Hk.f.&T.	Ghoge' Champ
Magnolia sp.	Khanakpa; Okhane'
Mahonia nepaulensis DC.	Chatri
Maianthemum purpureum (Wall.) La	Saccar Khanda
Meconopsis napaulensis	Poppy
Merriliopanax alpinus (Cl.) Harms.	Ghiu Paat; Bhalu chinde
Mikania sp.	Saccar Khanda
Monachosorium henryi H. Christ.	Mirmire1
Myriactis wallichii Less.	SAL; Aalu Pate
Myrsine semiserrata	Khalme'
Neilla thyrsiflora Sims.	Sipsipe'
Neolitsea foliosa (Nees) Gamble	Sisi Phul
Ophiopogon intermedius D. Don	Bhui Ateej
Oplismenus compositus	TAB
Osmanthus suavis King ex Cl.	Sipsipe2, Sirlinge
Oxalis acetosella L.	Bhui Putali
Oxyspora paniculata (D. Don) DC.	UN
Paris polyphylla Sm.	Satwa
Persicaria barbata (L.) Hara	Ratnuale; Rato Thotne
Persicaria chinensis (L.) Gross	SPD
Persicaria nepalensis (Meissn.) H. Gross	UniD BKB
Persicaria sp.	Piro Thotne
Persicaria sp.2	Raat Naulo
Phleum alpinum L.	Gau jhaar7
Phoebe attenuata (Nees) Nees	Lapche Kawla; UnID BPH
Photinia integrifolia Lindl	Bakalpate'
Phryma leptostachya L.	Ulte Kudo
Pieris formosa (Wall.) D. Don	Limbuni Phul
Pilea bracteosa Wedd.	Ankhein Ghas
Pilea sp.	UnID FGL
Pimpinella diversifolia DC.	UnID RTH
Piptanthus nepalensis (Hk.) Sw.	Larim
Plantago erosa Wall.	Nasey Jhaar
Plectranthus sp.	Lal Pate'; SMG; WBK
Poa annua L.	SFH
Poa pratensis L.	Gau ghas
Poa sp.2	Syano gaughas
Polystichum lentum (D. Don) Moore	Kalo unew

Polystichum sp.	Thulo unew
Fragaria nubicola nepalensis D. Don	Kukur Aiselo
Fragaria nubicola leuconota D. Don	UN
Fragaria nubicola peduncularis D. Don	UN
Primula denticulata Sm.	Primula2
Primula edgeworthii (Hk.f.) Pax	UnID GPR; Bhui Primula
Primula sikkimensis Hk.f.	Primula
Prunus nepaulensis (Ser.) Steud.	Badaam
Pteridium revolutum (Bl.) Nakai	Unew9
Pteris cretica L.	Thulo unew
Pteris biaurita L.	Unew7
Quercus lamellosa Sm.	Bajrath
Ranunculus diffusus DC.	UnID PP; PWP
Ranunculus laetus Royle	UnID PPH
Ranunculus sp.	Saili
Rheum acuminatum Hk. F	Khokhim
Rhododendron arboreum Sm.	Lali Gurans
Rhododendron arboreum ssp. cinnamomeum	Lali Gurans2
Rhododendron barbatum G. Don	Junge' Chimmal
Rhododendron campanulatum D. Don	Chimmal
Rhododendron campylocarpum Hk.f.	Chimmal2
Rhododendron cinnabarinum	Chimmal3
Rhododendron falconerii Hk.f.	UN
Rhododendron fulgens Hk.f.	UN
Rhododendron grande Wt.	UN
Rhododendron griffithianum Wt.	Nange Chimmal
Rhododendron hodgsonii Hk.f.	UN
Ribes glaciale Wall.	TPW
Rosa sericea Lindl.	Khursani kada
Rubia manjith	Majeto
Rubus ellipticus Sm.	Aul Aiselo
Rubus calycinus Wall. Ex D. Don	UnID RTT; TTT2
Rubus macilentus Camb.	Ainsalo kanda
Rubus nepalensis (Hk.f.) Kunz.	TRT; TLC
Rubus paniculatus Sm.	STH; Kandakari
Rubus pentagonus Wall. Ex Focke	Putali Ghas;
Rubus sp.	Jal Thange
Rumex nepalensis Spreng.	Hal Hale
Sarcococca saligna (D. Don) Muel.-Arg.	Chyapate
Sarcococca wallichii Stapf.	Labarpate'
Saurauia nepaulensis DC	Amilo Pate
Schefflera bengalensis Gamble	Paanch Pate'
Schefflera impressa (Cl.) Hrarms	Ramar
Scutellaria sp.	SSH
Senecio chrysanthemoides	Senecio chrysanthemoides 2
Senecio sp.	STR; TKB; Tori Phul

Selaginella pennata (D. Don) Spring	UnID MSG
Skimmia laureola (DC.) Walp.	Raini Phul
Smilacina purpurea	Kheerole
Smilax myrtillus A. DC.	Chelse
Sorbus microphylla Wenz.	Bajhar
Spiraea bella Don	UnID GTH
Stellaria media	Jungli Simraya
Strobilanthes atropurpureus Nees	UnID LMR; WHK
Strobilanthus pectinatus T. And.	Lal Pate'
Strobilanthessp.	Khorsani Kib
Swertia sp.	UnID CH
Symplocos glomerata King ex Cl.	Thulopate Kharane
Symplocos lucida (Thunb.) Sieb. & Zucc.	Khalame'; TLK
Symplocos sp.	Bakilopate
Synotis alata (Wall.) Jeff. & Chen.	UN
Tetrastigma serrulatum (Roxb.) Planch.	UnID CWH
Thalictrum chelidonii DC	UN
Thalictrum foliolosum DC.	UnID RGH
Thamnocalamus spathiflorus (Trin.) Munro	Rato Ningalo
Thelypteris cana (J. Sm.) Ching	Unew8
Thlaspi arvense L.	UnID OPH
Tricyrtis maculata (D. Don) Macb.	Sacca Khanda
Triplostegia sp. (?)	SSM
Tsuga dumosa (D. Don) Eich.	Thingre Salla
Urtica ardens Link.	Shishnu
Urtica dioica L.	Ghare' Shishnu
Vaccinium glauco-album Hk. f ex Cl.	Rukh Gurans
Valeriana sp.	SLA
Viburnum erubescens Wall. Ex DC.	Asare'
Viburnum nervosum D. Don	Ambre'
Viola biflora L.	UnID HSP
Viola pilosa Blume	Simi Jhaar
Yushania maling (Gamble) Majumdar	Malingo
Yushania racemosa (Munro) Majumdar	Haange Malingo
Zanthoxylum acanthopodium DC.	Boke Timbur
Zanthoxylum armatum DC.	Timbur
Zanthoxylum oxyphyllum Edgew.	Sil Timbur

APPENDIX 2: ANOSIM results for comparison of species composition for pasture and buffer areas across different livestock grazing levels.

Herbaceous species composition within pastures:

Pair	*r -ANOSIM*	*Significance*
Abandoned - - Lightly	0.2252	0.001
Abandoned- - Heavily	0.3882	0.001
Lightly -- Heavily	**0.4236**	**0.001**

Herbaceous species composition in forested buffer areas:

Pair	*r -ANOSIM*	*Significance*
Abandoned - - Lightly	0.2053	0.001
Abandoned - - Heavily	0.103	0.001
Abandoned - - Never	0.1519	0.001
Lightly - - Heavily	**0.5352**	**0.001**
Lightly - - Never grazed	**0.5801**	**0.001**
Heavily - - Never grazed	0.2581	0.001

Woody species composition within pastures:

Pair	*r -ANOSIM*	*Significance*
Abandoned - - Lightly	0.06832	0.22
Abandoned- - Heavily	0.3998	0.001
Lightly -- Heavily	**0.4546**	**0.001**

Woody species composition in forested buffer areas:

Pair	***r -ANOSIM***	***Significance***
Abandoned - - Lightly	0.08335	0.001
Abandoned - - Heavily	0.2433	0.001
Abandoned - - Never	0.2344	0.001
Lightly - - Heavily	0.09588	0.008
Lightly - - Never grazed	0.05134	0.145
Heavily - - Never grazed	0.05881	0.033

APPENDIX 3: SIMPER results for species which contributes most to the compositional dissimilarity between different grazing levels

PASTURE HERBS

Lightly grazed -Heavily grazed	**Given metric**	**Cumulative contribution**	**Individual contribution**
Carex longpipes	0.1304045	13.04045	13.04045
Gaultheria nummularioides	0.2317574	23.17574	10.13529
Cyrtococcum accrescens	0.3040604	30.40604	7.2303
Carex japonica	0.3666651	36.66651	6.260469999
Pennisetum clandestinum	0.4283487	42.83487	6.16836
Carex duthiei	0.4762727	47.62727	4.7924
Rumex nepalensis	0.5236417	52.36417	4.736900000
Luzula spicata	0.5695009	56.95009	4.5859199
Carex sp.	0.6145966	61.45966	4.50957
Senecio chrysanthemoides	0.6584752	65.84752	4.38786
Fragaria nubicola	0.7014526	70.14526	4.29774

BUFFER HERBS

Lighly grazed –Heavily grazed	**Given metric**	**Cumulative contribution**	**Individual contribution**
Gaultheria nummularioides	0.1839907	18.39907	18.39907
Carex duthiei	0.2878757	28.78757	10.3885
Luzula spicata	0.3536103	35.36103	6.57346
Gaugleto	0.4045338	40.45338	5.09235

Carex longpipes	0.4498057	44.98057	4.52719
Fragaria nubicola	0.4879296	48.79296	3.81238999999
Pilea bracteosa	0.5206144	52.06144	3.26848
Rubus calycinus	0.5491341	54.91341	2.8519700000
Carex sp.	0.5763788	57.63788	2.72447
Aloo.Paate	0.6016907	60.16907	2.5311900000
Rubus sp.	0.623059	62.3059	2.1368299
Senecio chrysanthemoides	0.6444216	64.44216	2.136259999
Carex sp.	0.6634766	66.34766	1.9055
Clover.type	0.6809491	68.09491	1.747250000
Hemiphragma heterophyllum	0.6978975	69.78975	1.69484
Anaphalis royleanus	0.714607	71.4607	1.67095

Lightly grazed – Never grazed	**Given metric**	**Cumulative contribution**	**Individual contribution**
Gaultheria nummularioides	0.1996	19.96	19.96
Carex duthiei	0.3134	31.34	11.38
Gaugleto	0.412	41.2	9.86
Luzula spicata	0.4843	48.43	7.23
Rubus sp.	0.5277	52.77	4.34
Carex sp.	0.5672	56.72	3.95
Pilea bracteosa	0.605	60.5	3.77999999
Rubus calycinus	0.6364	63.64	3.140000
Bhui.Chichimira	0.6593	65.93	2.29

Carex sp.	0.6799	67.99	2.06
Carex longpipes	0.6998	69.98	1.99
Euonymus sp.	0.7189	71.89	1.91

PASTURE WOODY

Lightly grazed -Heavily grazed	**Given metric**	**Cumulative contribution**	**Individual contribution**
Berberis hookeri	0.3556076	35.56076	35.56076
Viburnum erubescence	0.6310016	63.10016	27.5394
Rosa sericea	0.8795702	87.95702	24.85686

APPENDIX 4: SIMPER results for seedling species composition

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Cumulative contributions of most influential species:

$`Never grazed_Lightly grazed
Lindera sp.             0.4831171
Rhododendron arboreum   0.6457473
Rhododendron grande     0.7424857

$Never grazed _Abandoned pasture
Lindera sp.                 0.3376274
Symplocos theifolia         0.5992967
Rhododendron grande         0.6884915
Duabanga grandiflora        0.7436907

$Never grazed_Heavily grazed
Lindera sp.             0.4561488
Rhododendron grande    0.5793962
Eurya acuminata        0.6764423
Symplocos theifolia    0.7690471

$Lightly grazed_Abandoned
Symplocos theifolia        0.3049245
Rhododendron arboreum      0.4494180
Lindera sp.                0.5483738
Duabanga grandiflora       0.6133099
Eurya acuminata            0.6661318
Symplocos lucida           0.7176426

$Lightly grazed_Heavily grazed
Lindera sp.               0.2071515
Rhododendron arboreum     0.3844012
Eurya acuminata           0.4920597
Symplocos theifolia       0.5968087
Ilex dipyrena             0.6633370
Symplocos lucida          0.7272201

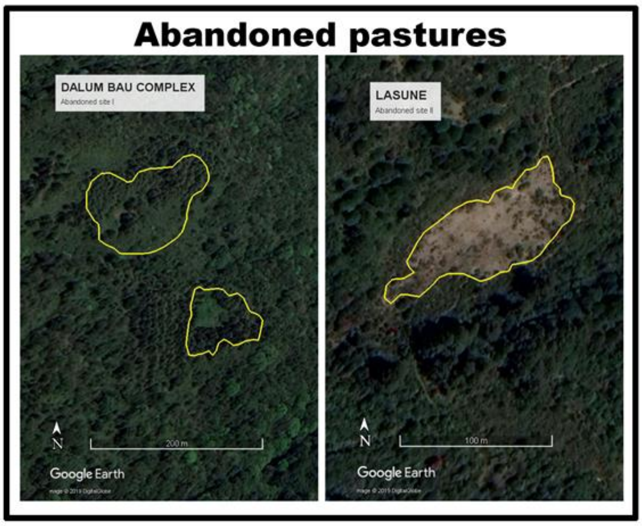
$Abandoned_Heavily grazed
Symplocos theifolia      0.2625375
Lindera sp.              0.4472542
Eurya acuminata          0.5433770
Symplocos lucida         0.6193924
Duabanga grandiflora     0.6747270
Machilus odoratissima    0.7135139
```

APPENDIX 5: Models to determine factors influencing seedling density

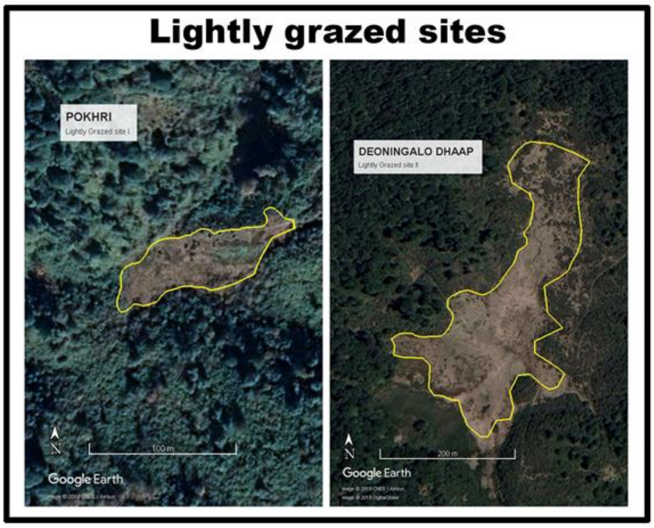
Sl. No.	Model predictors for seedling density	Df	AIC
1	Livestock grazing level, slope, shrub volume, position of plot	8	1414.52
2	Shrub volume, position of plot, livestock grazing level	7	1421.81
3	Livestock grazing level, slope, shrub volume	7	1422.64
4	Livestock grazing level, overstorey density of trees, shrub volume, bamboo cover	8	1424.39
5	Shrub volume, position of plot, understorey type	7	1427.80

APPENDIX 6: Models to determine factors influencing sapling density

Sl. No.	Model predictors for sapling density	Df	AIC
1	Shrub volume, position of plot, livestock grazing level	7	1974.64
2	Livestock grazing level, slope, shrub volume, position of plot	8	1976.42
3	Shrub volume, position of plot, understorey type	7	1990.54
4	Livestock grazing level, overstorey density of trees	6	1997.69
5	Livestock grazing level, overstorey density of trees, shrub volume, bamboo cover	8	1999.46



Abandoned pastures



Lightly grazed sites

Heavily grazed sites

Figure 15: Satellite imagery of the 7 pastures that were sampled.