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Impact of Tree Felling on Forest Regeneration and Biodiversity in Watershed Ecosystems: An Assessment of Vegetative Recovery, Species Composition, and Human Influence in Themnangbi-Jaibab Watershed

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ABSTRACT: The Mongar watershed is a critical resource for the local communities, providing water and supporting biodiversity. However, there has been limited assessment of the forest regeneration in areas affected by selective tree felling, grazing, and developmental activities. This study aims to evaluate the regeneration status within the watershed, focusing on the impacts of tree felling and cattle grazing across three forest types: broadleaf forests, Bhutan pine forests, and chirpine forests. Systematic sampling plots were established in areas where tree felling and grazing occurred, with a total of 50 main plots and 322 sub-plots surveyed.

The study identified nine timber-valuable species, with *Pinus bhutanica*, *Pinus roxburghii*, *Schima wallichii*, and *Juglans regia* being the most prominent. In addition, 28 understory species were recorded, with the highest intensity of cattle grazing observed in the broadleaf forests. Despite the pressures from grazing, overall forest regeneration was not deemed to be under immediate threat. However, the study highlights the need for improved monitoring and management of cattle grazing in upper forest areas to prevent long-term degradation.

The findings suggest that while regeneration is ongoing, certain species, particularly in heavily grazed areas, may require targeted interventions such as enrichment planting and rotational grazing strategies. The study concludes that sustainable forest and watershed management practices must be implemented to balance human use and ecological integrity, ensuring the long-term resilience of the Mongar watershed.

KEYWORDS: Forest regeneration, watershed, cattle grazing, biodiversity, tree felling, forest management.

I. INTRODUCTION

As outlined in the Forest and Nature Conservation Rules & Regulations 2017 (FNCRR 2017) (DoFPS, 2017), the development of a watershed management plan is mandatory for watersheds classified as "degraded" or "critical" based on the watershed classification guidelines established by the Watershed Management Division (WMD, 2010). These plans are essential to mitigate the degrading influences within such watersheds and aim to restore them to a "normal" or "pristine" condition.

The Integrated Watershed Management Plan for the Themnangbi-Jaibab Watershed in Mongar has been in effect from July 2018 to June 2023, covering a five-year period. This watershed is a vital water source, serving the Mongar municipality, Mongar Referral Hospital, Wengkhari Research Center, and local schools. Effective management is crucial to maintaining the integrity of this resource and ensuring its sustainable use.

The Themnangbi-Jaibab watershed is located within Mongar geog and comprises two villages, Themnangbi and Jaibab. The watershed lies within the Gang-gola block of the Korila Forest Management Unit (FMU), under the Territorial Forest Division in Mongar. It has been designated as a watershed working circle since the initial management plan of

the FMU, implemented in 1995. The total area of the watershed is 1,645.5 hectares, with an elevation range from approximately 1,600 to 2,800 meters above sea level. The watershed supports 59 households, with a population of 6,000 people benefiting from its resources downstream.

Ecologically, the watershed falls within the dry sub-tropical agro-ecological zone, characterized by broadleaf forests in the upper catchment and chirpine forests at the lower elevations. According to the management plan for the Korila FMU, the growing stock of the forest in the watershed is estimated at 53.34 m³ per hectare, reflecting the forest's capacity to provide timber and other ecosystem services. Sustainable management practices are imperative to preserving both the ecological functions and the resources provided by the watershed to the surrounding communities.

Objectives

- Assessment of regeneration status in openings created by tree felling
- Assessment of regeneration in the three different forest types

II. MATERIALS AND METHODS

Sl. No.	List of equipments	Purpose
1	Garmin GPS (62 S)	Navigation/locating plot/recording plots
2	Compass	Orientation
3	Diameter tape (5m)	Measurement of DBH
4	Measuring tape (50m)	Measuring quadrat plot and distance
5	Binocular	Observe the plant species and wildlife presence
6	Camera	Capturing photo
7	Fieldwork sheet	Field data record
8	Ribbons	Plots layout
9	Clinometer	Gradient

Materials used in collecting research data are Global Positioning System (GPS), measuring tapes, Sunnto Compass, Sunnto Clinometer, diameter tape, ribbons, and data collection forms

Field guide books such as Flowers of Himalaya (Polumin & Stainton, 2008), Flowers of Himalaya: A Supplement (Stainton, 1989), Weeds of Bhutan (Parker, 1992), Low Altitude Medicinal plants of Bhutan (Wangchuk & Samten, 2009) and Flora of Bhutan Vol. I Part 1, 2, 3, Vol. II Part 1, 2, 3, Vol. III Part 1, 2 (Grierson et al., 1983-2003) were being used for plants identification.

2.1 Sampling design and methods

With the help of local farmers and foresters the opening inside the watershed due to tree felling, grazing, and developmental activities was being identified. After site identification, systematic sampling with sampling plots of 5 x 5 m quadrants and 1 x 1 m quadrants within 5 x 5 m were laid out in case of herbs and shrubs, a total of 322 sub-plots were laid out. In each plot, herbaceous ground plants were identified, counted, and measured. Counting of the vegetative parts species was carried out to find invasive, exotic species and floristic composition in the openings created. The methods were adopted by Dr. Pema Wangda and Dr. Ohsawa.

Sampling intensity was being kept at 30% so a total of 50 main plots were being laid in the watershed depending upon the different forest types as follows:

Sl.no	Forest Types	Area %	Number of plots
1	Broad leaf forest	84.42	42
2	Blue pine Forest	5.87	3
3	Chirpine forest	9.71	5

A minimum of 14 sample sub-plots were surveyed representing all the opening areas. The purpose of using quadrat was to establish a standard area for examining the vegetation. Ground vegetation with the tallest height (cm) of each species and its coverage (%) was recorded to get volume, diversity, richness, and dominance. For the regeneration

survey, all seedlings and saplings occurring within the plot were identified and their height and age were estimated by counting branch tiers and/or bud-scale scars (Wangda & Ohsawa, 2006).

2.2 Data analyzing

3.2.1 Vegetation analysis

'Species relative density (RD, %) from height and coverage (Volume, m³) of each species was used. The dominant species of the plots were determined based on the dominance analysis species diversity index (H') and was calculated using "Shannon and Wiener Diversity Index and species evenness (J') was calculated". The preliminary data computed and was processed using PivotTable of the Microsoft Excel.

$$\text{Shannon Diversity} = H' = \sum_{i=1}^s p_i \cdot \ln p_i$$

$$\text{Evenness} = J = \frac{H}{\ln S}$$

$$\text{Richness} = \frac{N - 1}{\log N}$$

Study area

The Themnangbi-Jaibab watershed is located in Mongar geog and consists of two villages namely Themnangbi and Jaibab (Figure 1). It has a total area of 1645.5 ha with an elevation ranging from about 1600 to 2800 masl. There are 59 households in the watershed with a population of 6000 people in the municipal area which are the beneficiaries located downstream of the watershed. A total of 50 plots were being laid out for a regeneration survey within the watershed area. The plots were being laid out in the openings created due to the felling of trees, openings due to grazing and developmental activities. The plot laid out also assumed the different forest types inside the watershed area. Similarly, four plots for the collection of herbs data (North, East, and West & South) was laid out in each plot.

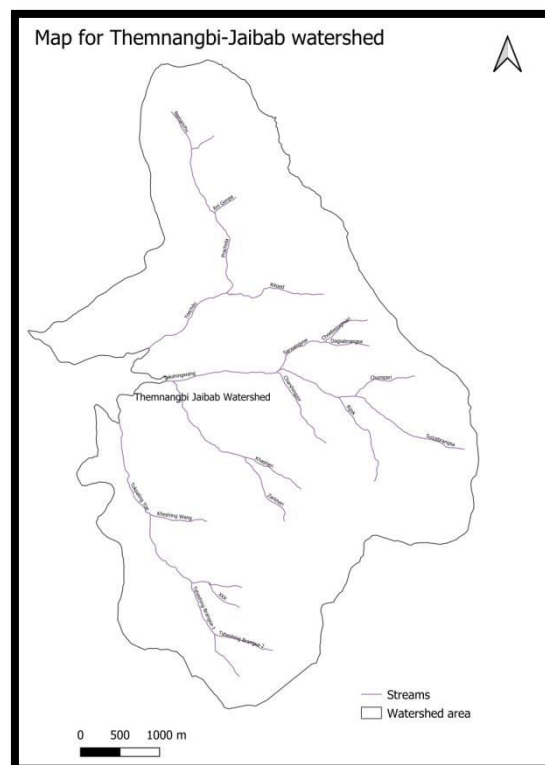


Figure1 Watershed area

The watershed falls under the dry sub-tropical agro-ecological zone with broadleaf forest in the upper catchment and chirpine forest towards the base of the watershed. As per the management plan for korila FMU, the growing stock in the FMU consisting of the watershed is 53.34 m³ /ha.

III. RESULTS AND DISCUSSIONS

Human pressure on the forests of Bhutan is moderate to low due to the low population density (16 person km²) (PHCB 2005) and are mainly traditional types. Such small-scale impacts may favor stable regeneration of broad-leaved species of humid forests (Wangda & Ohsawa, 2006).

Resource allocation is only done through single tree selection and cable line operation is not allowed, however higher exploitation of forest (illegal and legal) and forest fires in the watershed are issues being reported. Increasing accessibility in forest areas due to farm road construction and increasing population in the watershed is expected to increase the pressure on forest and resource extraction. The following quantities of forest produce were being allocated from the watershed area as follows:

Table 1: Quantity of forest produce supplied from watershed area 2014-2017

Tree	Cham	Pole	Fencing post	Flag post	Firewood
61 nos	43 nos	462 nos.	320 nos	390 nos	980 m ³

The status of regeneration inside the watershed was being classified as timber and non-timber species. Timber valued species consisted of species that were being used by the people for house constructions.

The study revealed a total of 9 timber valued species found inside the watershed area (figure 2). The study revealed higher percentage regeneration growth of *Pinus bhutanica* followed by *Pinus roxburghii*, *Schima wallichii* & *Juglans regia*. However, the forest in the opening created due to tree felling has cattle’s freely graze inside the watershed area. Sampling data were being collected based upon the 3 different forest types; 1) Broadleaved/Broad-leaved forests 2) Bhutan Pine Forest and 3) Chirpine forest.

Broadleaved forests were being dominated by *Symplocus*, *Quercus* spp, *Schima wallichii* & *Daphniphyllum chartaceum*. Bhutan pine forest mainly consisted of *Pinus bhutanica* & *Quercus griffithii* with main understory plants *Anaphalus* and *Pteridium* spp. Chirpine forest mainly consisted of *Pinus roxburghii* with main understory plants such as *Desmodium* spp, & *Cymbopogon* spp.

The intensity of the cattle grazing in the watershed is higher in the broadleaved forests compared to the other two. Excessive cattle grazing and trampling by the cows have to be monitored to protect the seedling of *Juglans regia*, *Michelia exelsa*, and *Betula*.

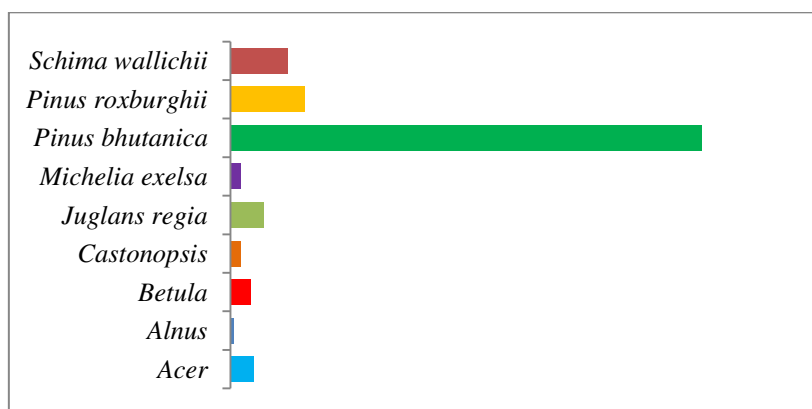


Figure 2 Regeneration status of timber species used for construction purposes

People selectively felled timber and create gaps in the pine forest at lower altitude. As per Wangda & Ohsawa, 2006, these gaps facilitate shade-intolerant pine seedlings, and so produce a peculiar forest structure, i.e. the mono-specific pine forest consisting of spatially segregated patch-mosaic stands of various aged pines.

Non-timber species include those tree species which are not being used for the construction purpose however they are used as firewood or for other non-wood forest production by the communities. The study revealed a total of 19 non-timber species as listed below (figure 3). The dominant regeneration of non-timber species found in the watershed is *Symplocos* spp., *Quercus griffithii*, and *Daphniphyllum chartaceum*.

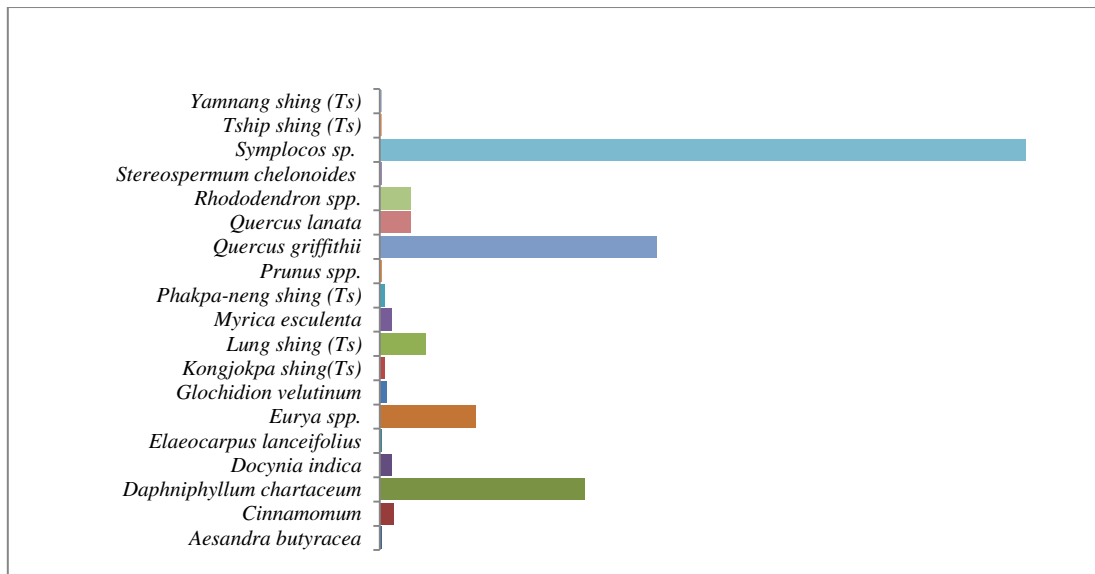


Figure 3 Status of non-timber species within the watershed

Average tree height is an important environmental factor that significantly affects the density of seedlings and saplings. The average height attained by the saplings of timber species was 25.9 cm. The highest height attained was by *Alnus* (50 cm), followed by *Schima wallichii* (41.6 cm).

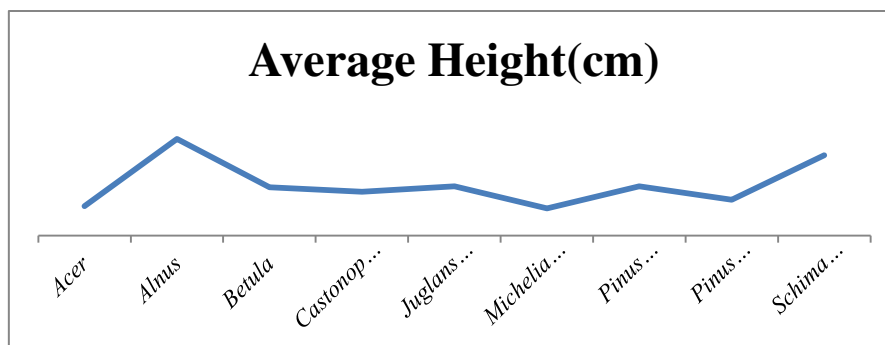


Figure 4 Average height of timber sapling species wise

Similarly, non-timber species height comparison as shown in (figure 5) below depicts the majority of the species in 0-25 cm height range.

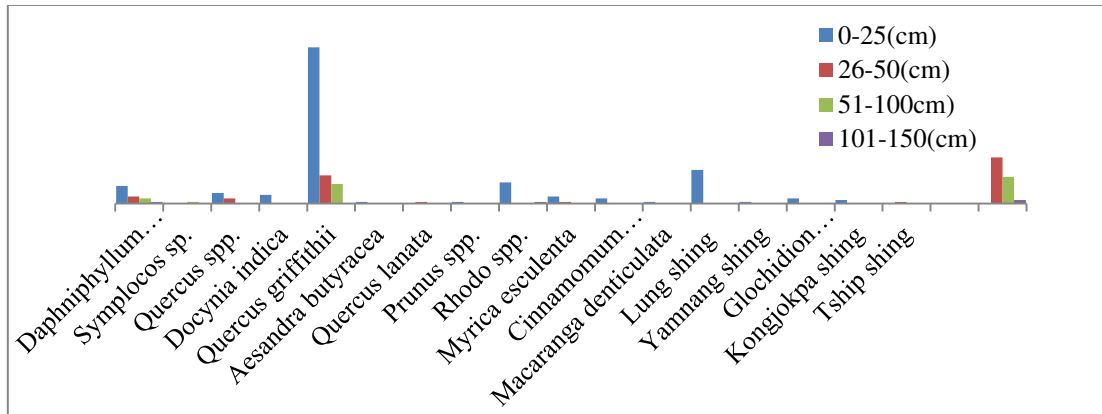


Figure 5 Average height for non-timber species

3.1 Species Diversity & Species abundance

Based on the Shannon diversity index (H'), the watershed recorded a diversity value of 0.62 with the most dominant sapling trees *Symplocos* species followed by *Pinus bhutanica*. The species evenness was 29 different types of tree species found within the watershed area.

Lorenz curve is a graphical representation of the distribution of income or wealth. It was developed by Max O. Lorenz in 1905 for representing inequality of the distribution (figure 6). The concept is useful in describing inequality among the size of individuals in ecology and in studies of biodiversity, where the cumulative proportion of species is plotted against the cumulative proportion of individuals. So as per the Lorenz graph, the equality of species distribution is more of an uneven in the watershed area.

The change of species composition inside the watershed from dry pine type through the mixed pine-oak, to the mesic broad-leaved type, occurred as a response to both humidity gradients from xeric to mesic climatic conditions and successional gradient from pioneer pine to seral and climax oak broad-leaved forests (Wangda & Ohsawa, 2006).

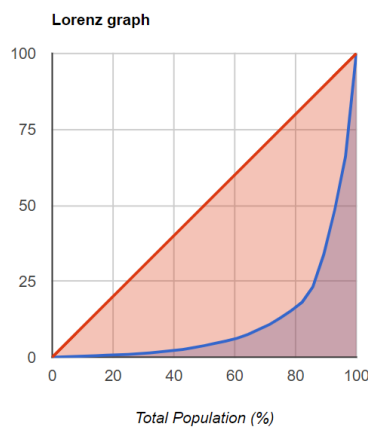


Figure 6 Lorenz graph

3.2 Undergrowth found in different forest types

The main undergrowth species found within the watershed are *Desmodium*, *Eupatorium*, *Viburnum*, *Fragaria*, and *Anaphalus*. A total of 28 main understory species were being recorded in the watershed (figure 7). The result of this finding was similar to the findings of Teketay (1999) who reported that the tree species are associated with a wide range of shrubs, herbs, and grasses. Swamps are dominated by sedges, grasses, and herbs.

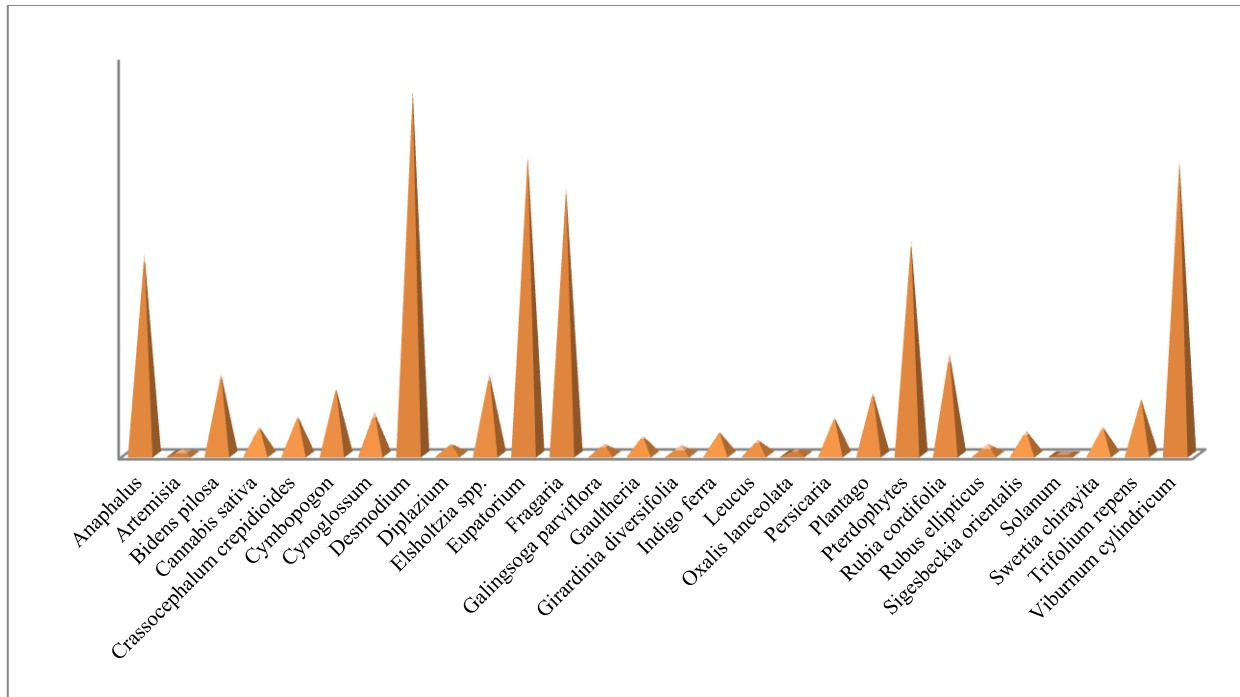


Figure 7 Understory plants inside the watershed

An invasive species is one that is not native to an ecosystem and whose introduction does or likely to cause economic and environmental harm. Invasive species are a serious growing problem worldwide, it occupies faster in abandoned land (Perry et al., 2008).

The plant species arrived from other continents and are often referred to as exotic, alien, introduced," or "nonnative" invasive. In Bhutan, NBC (2010) defines “those exotic plants introduced outside their natural habitats either intentionally for agriculture and horticulture purposes or unintentionally through trade and tourism. Such introduced plants with the potential to compete and replace native species and alter functions and structures of the natural ecosystems, posing a great threat to native species are referred to as Invasive alien plants”.

However based upon the different forest types, the main undergrowth are as shown below:

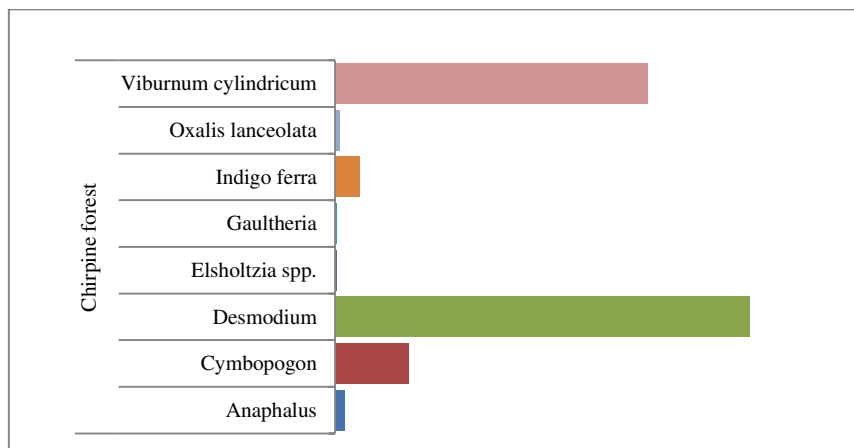


Figure 8 Undergrowth compositions in Chirpine forests

The chir forests are found at an altitude of 900-1800 m. *Pinus roxburghii* serves as an important source of timber, firewood, and litter for cattle bedding in the Bhutan Himalaya (Wangda & Ohsawa, 2006). Main undergrowth in chirpine forest composed of *Desmodium* spp and *Viburnum cylindricum* (Figure 8).

Similar results to studies being conducted by Wangda & Ohsawa, 2006 were being revealed for all three types of regeneration (inverse-J, sporadic, uni-modal) depending on altitude, human use, and biotic factors.

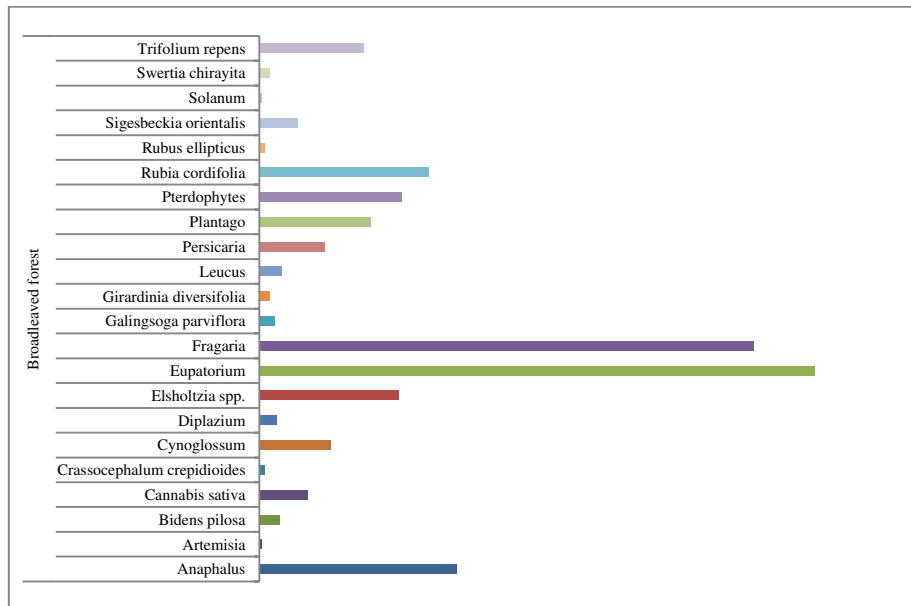


Figure 9 Undergrowth compositions in Broadleaved forests

Relatively higher numbers of undergrowth plants were being found in broadleaved forest compared to the other two. The main undergrowth composition in broadleaved forests consisted of *Eupatorium* spp., *Fragaria* spp and *Anaphalus* spp.

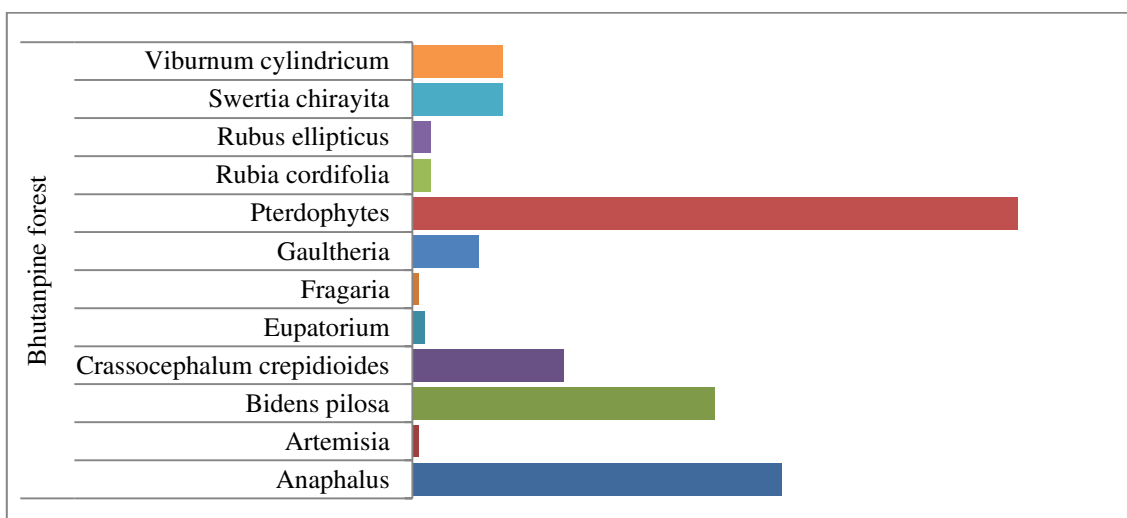


Figure 10 Undergrowth compositions in Bhutan pine forest

Pteridophytes and *Anaphalus* spp. were the major composition of undergrowth in the Bhutan pine forest. The blue pine forests occur in the temperate regions between 1800-3000 m. The blue pine is dominant and demonstrates fast colonization. It is sometimes found mixed with oak (*Quercus griffithii*) and rhododendron.

3.3 Discussions

The present study reveals that the anthropogenic disturbance cause changes in species composition and species density, and frequency. An increase in species number, density, and frequency of herbaceous community is due to disturbances. There was variation in species composition, evenness and diversity in the watershed area.

The human impact within the watershed was clear as open spaces left after selective tree felling for timber. These spaces may assist in the establishment of shade-intolerant species and regeneration of a mixed pine-broadleaved forest (Wangda & Ohsawa, 2006). Occurrence of *Pinus bhutanica* in few gaps also depicted past natural or human-caused disturbances that have enabled invasion of shade-intolerant pine inside the watershed. Evergreen trees such as *Symplocos* spp & *Quercus* spp. dominated understory, while less abundant species such as *Michelia exelsa*, *Juglans regia*, and *Betula* spp. were found to inhabit the gaps due to the past human-caused or natural disturbances.

Similar results to the study being conducted by (Wangda & Ohsawa, 2006) were being depicted in the watershed with the patterns of the density of seedlings and saplings of *Pinus roxburghii* & *Pinus bhutanica* regeneration continuous and of invasive type inside the plots. The young tree density tended to decline either due to human pressure or naturally, due to climatic conditions (drought) and biological interactions (Wangda & Ohsawa, 2006).

3.4 Recommendations

Similar regeneration trends as per (Wangda & Ohsawa, 2006) can be described in the watershed are too as 1) Invasive at the lower, warm, relatively dry forest: 2) Stable/balanced at the mid-altitude, moist evergreen broadleaved forest. Variation partitioning in the stories of both seedlings and saplings indicated that the order of importance was soil properties > forest characteristics > topography, which confirmed that soil properties have a large impact on regeneration establishment (Taylor & Francis, 2019). Maintaining herb cover near 35% would be beneficial for the growth and survival of seedling species (Taylor & Francis, 2019).

The current study may conclude that the population of *Pinus roxburghii* & *Pinus bhutanica* is stable about its continuous and frequent reproduction as conclude similarly by Wangda & Ohsawa, 2006. Selective felling of a mature pine tree creates a small gap and accordingly mosaic of light canopy patches, favoring high density of seedlings and saplings within these patches. Such population structure is seen as inverse-J or sporadic type and indicates continuous or frequent reproduction of *Pinus roxburghii* (Wangda & Ohsawa, 2006). These our result have similar findings with (Saxena & Singh 1984), (Singh & Singh, 1992), & (Wangda & Ohsawa, 2006).

Regeneration dynamics compared for *Pinus roxburghii* by (Sangye, 2005) for three fire frequency classes showed bell-shaped dbh distribution in the no-fire class, high and moderate fire class showed reverse J-shaped distribution, however, the seedling densities were found abundant in the no-fire class than the moderate and high fire class. Since to date, only one case of forest fire case is being reported inside the watershed area, the regeneration of the pine forest is being not hampered extremely.

As per (Wangda & Ohsawa, 2006), small-scale human impact can also facilitate regeneration of major broad-leaved forest species such as, *Quercus griffithii*, *Quercus lanata*, and *Rhododendron arboreum*. *Quercus griffithii* regenerates fairly well in the gap and light canopy forest. On the other hand, evergreen *Quercus lanata*, can even regenerate in the closed-canopy forest, and these two oak species sometimes coexist and share the canopy. The two species are being used as fuel wood, fodder, and litter by farmers, so extraction on the selection basis and lopping of these trees and opening will enhance the regeneration. The findings are also being supported through similar studies being reported that small scale lopping enhances species richness and favored regeneration in the oak forest of central Nepal (Thadani & Ashton, 1995), (Vetaas, 1997). Appropriate thinning of stands with higher densities and closed canopies are expected to produce gaps and promote the natural regeneration. (Taylor & Francis, 2019)

The current study concludes that the regeneration of the forest within the watershed is not under threat; however, the excessive cattle grazing & trampling by cattle in the upper forest need to be monitored and in accordance with

management plans and enrichment activities be carried out. Further details study about the species wise timber, season-wise, soil, temperature, moisture content need to be conducted.

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