FLORISTIC COMPOSITION OF BRYOPHYTES AND ITS DIVERSITY ALONG THE ELEVATION GRADIENT OF PALPA DISTRICT, NEPAL

A DISSERTATION SUBMITTED FOR THE PARTIAL FULFILLMENT OF MASTER'S OF SCIENCE IN BOTANY

Submitted By

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DECLARATION

I, **Tulsi Neupane,** student of Central Department of Botany, hereby declare that the present work entitled "**Floristic composition of Bryophytes and its diversity along the elevation gradient of Palpa District, Nepal"** is the original research work carried out for the fulfillment of the Master's Degree in Science under the supervision of Associate Prof. Dr. Giri Prasad Joshi. I further ensure that this research work will not be submitted either in full or partial form for the fulfillment of other degrees or other academic awards in any other institution or University.

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LETTER OF RECOMMENDATION

This is to certify that the dissertation work entitled "**Floristic composition of Bryophytes and its diversity along the elevation gradient of Palpa District, Nepal**" has been completed by **Tulsi Neupane** under my supervision. This entire work was accomplished on the basis of candidate's original research work. To the best of my knowledge, the work has not been submitted to any other academic degree. I hereby recommend for acceptance of this dissertation as a partial fulfillment of the requirement of Master's Degree in Botany at the Institute of Science and Technology, Tribhuvan University, Nepal.

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LETTER OF APPROVAL

The M.Sc. dissertation entitled **"Floristic composition of Bryophytes and its diversity along the elevation gradient of Palpa District, Nepal"** submitted to the Central Department of Botany, Tribhuvan University, Kirtipur, Kathmandu by **Tulsi Neupane** has been accepted as partial fulfillment of the requirement of Masters of Science in Botany.

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Tulsi Neupane

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ABSTRACT

Bryophytes are very important groups of land plant with a varied ecological and economic importance. These are second most diverse group after angiosperm, though least concerned group in the field of research and documentation. Various studies have suggested making an initiation to promote research on various unexplored region of Nepal so as to complete the documentation process of bryoflora. The aim of this study is to record the floristic information of the bryophytes, its species richness in relation to various environmental variables including the soil macronutrient along the tropical and sub-tropical band Palpa district where no studies are taken place till date. Systematic random sampling methods was used where the circular plots of 10 m radius was laid with 5 (1 m x 1 m) subplots each. Similar 5 sample plots were laid 50 m in each elevation band. The elevation band of the study area was from 300 m- 1500 m where the plots were laid at an interval 300± 85 m depending upon the topography. In each plot various environmental variables were recorded such as elevation, canopy cover, bareground, rock cover, other plants, herb cover, bryophytes cover, organic carbon, nitrogen content, phosphorous, potassium. In total 39 species were collected from the study area with dominancy of mosses. The regression analysis showed statistically significant linear inclining relation with elevation gradient. Declining linear relation was found for canopy cover and total species richness and also for both liverworts and mosses but the variable was insignificant for the hornworts. Declining linear relation was also shown for bare ground and the relation with other plants species, rock cover, herb cover, herb cover and various soil parameter (Organic matter, Nitrogen, Potassium, Phosphorous) was insignificant but mosses showed significant declining relationship with Potassium content though various studies showed significant relations with the soil macro-nutrients. We expected that the study will give more species as compared to previous study done in the western region in the same elevation which was not true. So, there might be soil and rock parameters which may be the reason of low richness of the species. So, further research with soil micro-nutrients and rock parameter may suggest the clear reason of the low number of species.

Keywords : bryoflora, elevation gradient, environmental variable, species richness.

CHAPTER ONE : INTRODUCTION

1.1 Background

1.1.1 Bryophytes

The term bryophytes is the combination of two Greek words βρύον (brúon, "moss") and φυτόν (phutón, "plant"). The term bryophyte was first introduced by Robert Braun in 1864 collectively for algae, fungi, lichen and mosses (Chopra, 1998). Later on bryophytes were recognized as a separate group with three distinct lineages i.e., liverworts, hornworts and mosses (Smith, 1991). Bryophytes, the simplest non-vascular land plants, showing significant alternation of generation with dominant haploid stage in their life cycle. They absorb minerals, water, and carbon-dioxide directly through the cell wall as true vascular system are lacking. Bryophytes represents a group of plants which swell upon hydration (Vanderpoorten and Goffinet, 2009).Their physiological tolerance allows them to sustain in long period of dry condition, thus are able to colonize in a variety of substratum. Nearly all bryophytes are autotrophic in nature and prefer to grow on moist habitat.

The three lineages of bryophytes are distinguished morphologically. Their size varies from microscopic body i.e. *Nanomitrium austinii* (less than 1 mm) to very large body i.e. *Fontinalis dalacarlica* i.e. up to 166 cm (Takaki, 1984). They are the only group of land plants with dominant and branched gametophytes exhibiting diversity of morphologies unparalleled in tracheophytes (Crum, 2001). Among the three lineages, liverworts consist of both the thalloid and leafy forms. The thalloid forms are dorsi-ventrally flattened with the sporophytes mostly at the dorsal surface and scales and rhizoids on the ventral surface. Similarly, hornworts consist of dorsiventrally flattened gametophyte with long horned sporophytes. Unlike liverworts and hornworts, mosses look much more similar to the vegetative structure of higher vascular plants. They have branched leafy structure, actually part of gametophytic body and sporophytic body with long seta and a capsule. Among the lineages, mosses show greater morphological diversity in sporophytic generation especially in structure of capsule and peristome teeth which manages dispersal of spores.

Bryophytes have a long history on earth and believed to be established as earliest land plants evolved 470- 515.5 million years ago (Morris *et al*., 2018). They forms the basal clade of land plants (Nickrent *et al*., 2000). It has been reported that the spore bearing bryophytes were occurred and widespread at the end of the Ordovician period (Wellman *et al*., 2003) but Devonian period was considered as the fossil age for bryophytes (Schofield, 1985). So, bryophytes has long evolutionary history and are persistent from hundreds of millions years (Renzaglia *et al.*, 2007). Bryophyte serves as the bridge between the land and the origin of vascular plants by linking algal ancestors to seed bearing vascular plants (Vanderpoorten and Goffinet, 2009). Besides this, they also show similarity in physiological and morphological features with the higher land plants which suggests that they were the ancestors for the other land plants.

1.1.2 Distribution and diversity of bryophytes

Bryophytes are the second most diverse group among the plant kingdom after angiosperms (Buck and Goffinet, 2000). The diversification is because of the variation in life forms and their ability to grow in diversified habitats such as damp soil, rock, fallen rotten wood, water and tree trunk (Andrew *et al*., 2003). Various microclimatic factors such as rainfall, temperature, elevation and latitude also influence the distribution of bryophytes (Sveinbjornsson and Oechel, 1992). They occasionally grow on unexpected substrates, like the leather of a discarded boot, or a rusty iron pipe. In modern cities where air pollution and the man-made environment seem implacable, bryophytes colonize in crevices in masonry (Bates 2000). Along the gradients the distribution of bryophytes is also determined by soil or substrate pH, humidity, nutrient content, age of soil/rocks, and soil composition (Barkman, 1958; Sillett and Neitlich, 1996; Batty *et al*., 2003; Paudel, 2019). Bryophytes have capacity to tolerate high temperature, extreme desiccation and can also survive in extreme freezing conditions. These features support them to grow in a long range of diverse land areas from the tropics to the polar region around the globe. In Nepal, the distribution of bryophyte is found from lowland Tarai (62 masl) to high Himalayas (6500 masl) (Pradhan, 2016). However highest diversity is reported in the temperate region (Grau*et al.*, 2007).

Documentation of diversity and distribution patterns, and determining how those patterns are organized, is the first goal in biogeography. As Takhtajan (1986) recognized the floristic kingdoms to document the floral distribution pattern and diversity of various flora in the world, Schofield (1992) adopted this system for the world bryophyte flora. Nearly one third of the world's total bryophytes (ca. 4000 species) has been reported from Neotropics, of them highest species diversity and rates of endemism has been recorded in Northern Andes (Gradstein *et al*., 2001).

While looking towards the global diversity of bryophytes there is a brief estimation of the total number of species which varies according to authors such as Gradstein *et al.* (2001) states that there are about 15,000 of bryophyte species around the world, whereas Asakawa *et al.* (2013) reported 25,000 bryophyte species which was similar to the estimation of Klavina (2015), but Patiño and Vanderpoorten (2018) reported about 20,000 species. Asakawa *et al*. (2013) also listed the number of species in three lineages where the highest diversity is of mosses (14,000 species) followed by liverworts (6000 species) and hornworts (only 300 species). In the Asian continent highest diversity is recorded from China (3184 species), among them 2056 were mosses, 1102 liverworts and 26 species of hornworts (Song *et al.*, 2021). India which borders the maximum area of the Nepal has recorded 2562 taxa including 1636 mosses, 887 liverworts and 39 hornworts (www.bsienvis.nic.in/Database /Bryophytes_ 225889.aspx).

Nepal is a country lying along the southern slopes of Himalayan mountain range of Asian continent. It is surrounded by China in the north and India in east, west and south. In Nepal Francis Buchanan-Hamilton was the first to start bryophyte exploration. From that time the total bryophyte count till date is 1217 species (Pradhan, 2020) which is about 5% of the total bryophyte of the world, almost 50% of Indian bryophytes and about one third of Chinese bryophytes. The number of lineages shows similar pattern while looking around the world diversity and regional diversity. The highest diversity is of mosses with 771 species followed by liverworts with 435 species and lowest diversity is of hornworts i.e. 11 species (Pradhan, 2020). Similarly, the diversity of bryophytes in other south Asian countries has been documented as 568 species in Sri Lanka (O'Shea, 2002), 367 species in Bhutan (Gyeltshen *et al*., 2019) and 339 species in Pakistan (Higuchi and Nishimura, 2003). However, the lowest bryophyte diversity was reported from Bangladesh i.e. 247 species (https://en.banglapedia.org).

1.1.3 Floristic composition of bryophytes along elevation gradient

Floristic composition is also termed as species compositions is the sum of all species presents in specific area with a specific geographical composition. They also document the biotic and abiotic factors of a given geographical region which play a vital role in documenting plant diversity.

The relationship between species richness and elevation in a large elevation gradient usually come up with a hump-shaped graph. This trend is because of change in environmental condition with the increasing elevation gradient. First of all the temperature goes on decreasing while moving from tropical to alpine region. The decrease in temperature is a result of decrease in the air pressure. Similarly, the moisture content also varies in various geographical regions. But moisture content depends upon various other factors unlike temperature. Factors affecting soil moisture are soil properties i.e. physical, chemical and biological (Zhu and Lin 2011), climate (Montenegro and Ragab, 2012), vegetation (Vivoni *et al*. 2008), slope of hill, topography, rainfall, etc. As the bryophytes mostly grow on moist places, their high diversity in temperate region may be because of moderate temperature and high moisture content.

Several descriptive studies on bryophytes along the elevation gradient have been carried out in South America, Puerto Rico (Fulford *et al.*, 1971); in the Sierra Nevada de Santa Marta, Columbia (Van Reenen and Gradstein, 1983 and 1984); in Northeastern Peru (Frahm, 1987; Gradstein and Frahm, 1987); on Mount Kinabulu, eastern part of Borneo (Frahm, 1990); in Peru, Columbia (Churchill, 1991), Columbia (Kessler, 2000) and New Zealand (Pfeiffer, 2003) showed increase in bryophytes composition with increasing elevation and also suggests the sensitivity of bryophytes to climatic condition. Andrew *et al*. (2003) did not found significant pattern of bryophyte diversity with elevation on different mountains in Tasmania and New Zealand. Sun *et al*. (2013) in China; Grau *et al*. (2007), Sharma (2018) and Paudel (2019) in Nepal; are also some studies related to bryofloristic composition along an elevation gradients with various environmental conditions.

1.1.4. Significance of bryophytes

Bryophyte is substantial component of ecosystems with different ecological significance. Biological soil crust (biocrust) formation is an initial step to start primary succession on rock and nutrient lacking soils. At early successional series, soil or rock surfaces in many low-productivity ecosystems forms a "living skin" or biocrust (Belnap *et al*., 2003). Primarily, bryophytes along with filamentous algae, cyanobacteria, fungi and lichens are the main organisms to form biocrust (Belnap et al, 2003). Biocrust is a basics to establish other small plants. Bryophytes reduces the surface run off by water entrapment facilitating water infiltration and stabilize the soil surface (Zhang et al., 2009; Zhao *et al*., 2014).

Similarly, bryophytes play an important role in climatic regulation by influencing vegetation dynamics, soil formation, and characteristics of global biogeochemical cycle. Bryophytes play a fundamental role in the transport and transformation of carbon and basic nutrient elements as it contributes a considerable proportion of the global biomass in the ecosystems. *Sphagnum* demonstrates a key role in global biogeochemical cycles for sequestering large carbon quantities (Vitt and Wielder, 2009). Additionally, bryophytes are capable of forming symbiotic relationship with cyanobacteria that are efficient in fixing atmospheric nitrogen. For example, about 3 Kg/ha. nitrogen is fixed in boreal forests, of them one third to one half is fixed by *Nostoc* colonies which host on ubiquitous feather moss *Pleurozium schreberi* (De Luca *et al*., 2002). Despite being non-dominant, their ecological function in the global nutrient cycle has been diverse and disproportionate to their biomass. Besides this, they have capacity to grow in poor and exposed sites, accumulating an organic layer which provide suitable environment for micro- organisms and provide a seed bed for seedling contributing the vascular epiphytic biota of tropical forests (Benzing, 1990; Uniyal, 1999). Besides micro-organisms, small vertebrates are also benefitted by bryophytes as they live, feed and deposit their eggs on bryophyte turfs (Rhoades, 1995; Uniyal, 1999). Thus, the integrity of the bryophyte vegetation is fundamental for the maintenance of biotic and abiotic processes in tropics.

Some bryophytes such as *Tortula and Racomitrium* are best indicator of rocks type which grows on limestone and granite (Pradhan, 2020). Some bryophytes population such as *Marchantia polymorpha, Solenostoma crenulata, Ceratodon purpureus* and *Funaria hygrometrica* are some of the metal tolerant species. Besides this some bryophytes such as *Brachythecium rutabulum, Grimmia pulvinata, Orthotrichum diaphanum, Bryum capillare, Bryum argenteum, Tortula muralis, Rhynchostegium confertum* and *Hypnum cupressiforme* show survival and luxuriant growth in polluted environment (Govindapyari *et al.,* 2010).

Bryophytes are not only important from ecological aspect, they also show significant economic benefits. The interest on bryophytes seems to be increasing because of their use in fuel production and in horticulture. It is estimated that nearly half of the world's annual peat production is used for fuel. In 1995, 71 million m^3 of energy peat were produced among which carbon flux due to combustion was estimated to be 2.6 million tons per year which is about 0.4% of the flux due to all fossil energies (Chapman *et al*., 2003). Bryophytes have unbelieving importance which was ignored before because of its small size. Many bryophytes have now been found rich in various chemical compounds for curing diseases like ringworms, lung and skin diseases, inflammation, fever, heart problems, liver ailments in countries like China, India and Native America (Glime, 2007). They are also used in the production of chemical compounds with repellent and anti-microbial properties (Parker *et al*., 2000) which may have great importance in the agricultural field. Bryophytes are now also used for genetic fingerprint in forensic science in the places of crime scene (Virtanen *et al*., 2007).

About 70 species of bryophytes of Nepal are reported as economically important which includes 15 species of liverworts and 55 species of mosses (Pradhan and Shrestha, 2000). Semi aquatic bryophytes like *Monosoleneum tenerum* Griff., recorded from western lowlands of Nepal can be used as an aquarium plant (Pradhan *et al*., 2007). Various such importance can be known by extensive study of bryophytes which is lacking in the present time.

1.2. Justification of study

In context of Nepal, very few works has been done in this field and those works done are just limited to exploration and documentation of bryophytes. Even after 218 years of long exploration history, the basic process of documentation is still far from complete. Additionally, very few studies of bryophytes including diversity with other environmental gradient have taken place in Nepal. The selected studies have been carried out in the Central Himalayas by Grau *et al*. (2007); in Pulchoki hill, Central Nepal by Sharma (2018); and in Kailali, Far-West Nepal by Paudel (2019). In Nepal, variations in amount of rainfall throughout the country has been noticed so far, which decreases from eastern to western region (Pokharel *et al*., 2019). Additionally, seasonal precipitation decreases from the southern mountain ranges to the northern part of Nepal with some of the highest rainfall areas located on the southern slope of the highest mountains of Pokhara and Num (Dhar and Nandargi, 2005). The proposed study area represents more or less central region of Nepal. As the macroclimatic variation such as temperature and rainfall pattern has been resulted into variation in diversity of bryophytes (Porley and Hodgetts, 2005), it is believed that the proposed study area may have unique bryophyte diversity. Additionally, as the floristic composition and diversity of bryophytes along elevation gradient has previously been completed in Far-West Nepal (tropical and sub-tropical region) by Paudel (2019), the proposed work will explore floristic composition and diversity of bryophytes of Central Nepal.

1.3. Research Questions

- What is the status of floristic composition of bryophytes?
- How distribution pattern of bryophytes are affected by habitat type?
- Does the species richness pattern of bryophytes increases along increasing elevation?
- What is the species richness pattern of bryophytes in relation to various environmental variables?
- Does soil macro-nutrient have any significant impact on bryofloral diversity?

1.4. Research objective

The general objective of the study was to determine floristic composition and ecology of bryophytes along elevation gradient from Siddhartha Rajmarga of Palpa District, Nepal. The specific objectives include:

- To explore the floristic composition of bryophytes
- To assess the distribution pattern of bryophytes with respect to habitat type
- To determine the species richness pattern of bryophytes along elevation gradient
- To determine the species richness pattern of bryophytes with various environmental variables
- To determine the relationship between soil macro-nutrients and diversity of bryophytes

CHAPTER TWO: LITERATURE REVIEW

2.1. History of Exploration on Bryophytes in Nepal

Francis Buchanan-Hamilton (Scottish physician), who made significant contributions as a geographer, zoologist, and botanist while living in India, was firstly initiated bryophyte exploration from the vicinity of Kathmandu Valley, Central Nepal in 1802. *Musci nepalensis* by W. J. Hooker (1808) appeared as the first publication of mosses which includes 17 species of different localities of Nepal. Later, Wallich (1832) who was a Danish Physician and Botanist collected 114 species from Kathmandu and its vicinity which was preserved as Wallich collection in Kew, and was also included in the publication "*Illustration of the Botany and other branches of Natural History of Himalayan Mountains"* by Royle (1839) along with his own collection of 55 species from Western Himalayas. The exploration of bryophytes in Nepal can be categorized into 3 phases i.e. Early period (1800-1950); Mid period (1950-2000); Recent period (2000- till date).

Early period (1800 -1950)

This period was the initial period in the exploration of the bryophytes from Nepal. In this period the expedition works were very few with limited number of literature for the study and hence resulted in many new species to the world. Besides the personal visits of different explorers like Buchanan-Hamilton, Hooker and Wallich, there was a long gap in the field of botanical exploration in Nepal. The major exploration of bryophytes was carried out between 1850- 1900.

Mitten (1859) published the comprehensive account of mosses of Indian region with reference to Nepal. He designated 85 genera and 800 species of Moss including many new species. Among them 187 species of 52 genera were Nepalese species which comprised the collection of Hamilton, Gardner and Wallich from Nepal.

Schiffner (1899) in his monograph on liverworts included 35 species from Nepal among which 10 species and 2 varieties were recorded new to science.

Various International researcher traveled the less explored regions during the next 50 years from 1900-1950. Stephani (1925) in the monographic study of liverworts of world reported 62 liverworts of Nepal belonging to 32 genera and published in "Species Hepaticerum" (1924-27). The exploration was continuous from this period.

Dixon (1925) during his expedition to Mount Everest (1924) reported *Grimmia somervilli* from Rombuk Valley (4850-5300 m) which was described as a new record to science. Similarly, *Aongstroemia julacea* was the interesting record as it was the moss species found in the highest altitude i.e. 6,530 m.

Blatter (1929) recorded 119 moss species from High wavy mountain and Mount Abu of India among which 25 species are also found in Nepal.

Bruhl (1931) reported 141 moss species from Nepal. Kashyap (1924, 1934) also reported few potential sites for Liverworts in Nepal.

Dixon (1937) reported 202 moss species from Assam of India among which 77 species also occurs in Nepal.

Mid period (1950-2000)

In this period, the expedition was not limited to Individual. Various institutions were involved in the expedition. Among them, the major expedition institution includes British Museum; Tokyo University; National Science Museum, Tokyo; Royal Botanical Garden, Edinburg. The expedition was mainly focused on Eastern and Central Nepal.

In 1952, team of J.D.A. Stainton, W.R. Sykes, L.H. William and O. Polunin started the British Museum (Natural History) expedition which was mainly focused on the western region. During this period many bryophyte species were collected from Mugu, Jumla, Baglung, Pokhara, Chame and handed over to S.K. Pande for identification which was published in 1957. Besides this Japanese West Nepal expedition (1952-1953) and Geneva Expedition to Nepal (1952-1954) to the eastern region also took place in the same year. During this period the collection of Zimmermann was published by Noguchi (1964). Besides this Royal Botanical Garden, Edinburgh organized a series of expeditions on 1989, 1991, 1992 and 2001 mostly in eastern and central region of Nepal (Pradhan, 2016).

Horikawa (1955), Svihla (1956), Banerji (1958), Wadhwa and Vohra (1965), Kuwahara (1968); Mizutani (1979a, b) and Iwatsuki (1979a, b) from Kochi Himalayan Expedition to Annapurna area, Pradhan and Joshi (1986), Srivastava and Singh (1989), Heddepson and Harold (1990),Watanable and Higuchi (1991), Nath and Asthana (1992), Grolle and Vana (1992), Yuzawa and Koike (1994), Furuki and Long (1994), Long (1995), Long (1999a), Long (1999b) made remarkable contribution by introducing new records in the field of bryophytes from Nepal.

Grolle (1964); Joshi and Joshi (1991) reported the endemic species of bryophytes. There are total 31 endemic species till date as reported by Joshi and Joshi (1991). Besides this some cytological works were also carried out by Inoue (1973); Inoue and Higuchi (1990).

Recent period (2000- till date)

As the previous two periods showed the active participation of the various botanist from different corner of the world except some researchers at the late 90's were also from Nepal. This period showed active participation of Nepalese researchers along with foreigners. Pradhan made most significant contribution in exploring the Nepalese bryophytes in this period.

Pradhan (2000a) enumerated the bryophyte species from different localities of Nepal. Similarly, Pradhan (2000b) contributed by enumerating the bryophytes of Phulchowki Hill, Central Nepal where *Hypnum cupressiforme* was recorded as new species to Nepal.

Pradhan (2001) studied and reported the bryophytes of Swayambhu, Kathmandu and added three new species in the record i.e. *Trematodon mayebatae*, *Pseudotaxiphyllum elegans* and *Neckera besseri.*

Pradhan (2002) did extensive work in Bardia National Park and reported *Fissidens asplenioides* as a new species to Nepal.

Pradhan and Shrestha (2003) reported the bryophytes of alpine region i.e. 4000 m of eastern and central Nepal and listed 233 species.

Grolle *et al.* (2003) recorded *Gottschelia patoniae* as a new record from east Himalaya which was collected by Long (1991) from Jaljale mountain at 3880 m altitude.

Pradhan (2004) in her study of Chitwan and Nawalparasi reported *Neckera noguchiana* as a new record to Nepalese bryophytes.

Wilbraham and Long (2005) in their study from Sino-Himalayan region reported *Zygodon rupestris* from Sankhuwasabha, eastern Nepal as a new record to the country.

Similarly, Long (2005) reported 17 new species; Long (2006) reported 3 new species; Pradhan and Joshi (2006) reported 2 new varieties and 1 new species; Pradhan and Joshi (2007a and 2007b) and Pradhan *et al.* (2007) reported 1 new species each from different parts of Terai; Pradhan and Joshi (2009) recorded one more new species, Pradhan (2014a) again reported 3 new species; Gajurel *et al*. (2017) reported one new species and Pradhan (2018) reported 2 new species to Nepal. After 2018 no new record of bryophytes has been reported.

Besides the reports on the new records different scientists had also explored various parts of the country actively to contribute in the field of enumeration of bryophytes species of the country such as Townsend (2002), Grau *et al.* (2007), Pradhan and Joshi (2008), Pradhan (2013), Pradhan (2014b), Karki and Ghimire (2019), Sharma (2018), Paudel (2019), Sharma *et al.* (2021) etc.

The long exploration history of Nepalese bryophytes accounts 1217 species from the country.

2.2. Species richness pattern along elevation gradient

Gradstein *et al.* (1989) studied bryophytes of Colombian Andes along the wet, foggy western slope (1000-4500 m) and the drier eastern slope (500-4500 m) and found that Species richness increases with altitude with the largest diversity. Liverworts showed high diversity in the western slope, but in drier environment their number is lesser compared to that of mosses.

Grytnes *et al*. (2006) studied the bryophytes of western Norway along the elevation 310-1135 masl and found no statistical significance between bryophytes species richness and altitude and also concluded that moisture condition of the habitat have major effect on bryophyte communities.

Bruun *et al*. (2006) studied the bryophytes of Northernmost Fennoscandia along the elevation 250-1525 masl and found that both moss and liverworts showed increasing trend of species richness along the altitude.

Ah-Peng *et al*. (2007) studied the bryophytes of Lava flow in La Reunion along the elevation 250-850 masl found the increasing species richness along the altitude. They also found that diversity and distribution was firstly affected by altitude and secondly by substrates like mineral and vegetation.

Grau *et al*. (2007) studied the bryophytes of central Himalayas of Nepal at the elevation of 100-5500 masl and found hump shaped unimodel relationship between species richness and altitude with highest diversity at the mid elevation. The highest diversity was at 2800 m for liverworts and 2500 m for mosses. They also concluded that Nepalese liverworts don't support the Rapoport's elevation rule.

Vittoz *et al*. (2010) studied the bryophytes of Switzerland from tree-line to nival band and found the decreasing species richness of bryophytes with increasing elevation and also concluded that there are very few strictly alpine- nival bryophyte species.

Costa *et al.* (2015) studied the bryophytes of Itatiaia National Park between 600 and 2787 masl which includes study of both floristic composition and species richness. The study found that both species richness and distribution was not uniform. The highest species richness (145 taxa) was found in mid altitude (2100-2200 m) and also found the number of threatened species were also high with increasing elevation.

González *et al*. (2017) studied the bryophytes of Ecuadorean along the elevational range 2700-4000 masl and found hump-shaped relation with elevation and has the highest peak at 3300 masl.

2.3. Bryophytes and their relation with environmental variables

Vanderpoorten and Engels (2002) studied the distribution of bryophytes in Central Belgium and reported soil conditions, especially loam, sand, pebble content, and forest cover were the best predictors of species distribution.

Spitale (2016) studied bryophytes of Norway, Italian Alps and South Tyrol in the elevation between 900-1900 masl in 3 different substrata i.e. forest floor, deadwood, tree trunk. Species richness was less at low elevation and more richness was found on deadwoods in case of liverworts. In case of moss, species richness was higher in forest floor and dead wood as compared to tree trunk. Besides this, they found that temperature was the most important predictor for overall richness. This work also concludes that temperature, solar radiation, rainfall strongly affected the functional diversity and to a lesser extent, by canopy closure and the interaction between canopy and rainfall.

Paudel (2019) studied the bryophytes of Kailali, Far West Nepal and found 89 species between the elevation range of 150-1600 m. This study was not limited to floristic exploration of bryophytes but also considered various environmental variables such as different habitats and various bioclimatic conditions and various soil parameters such as moisture and pH. The relation was found by using various multi- variate analysis such as Canonical Correspondance Analysis (CCA), Detrended Correspondance Analysis (DCA).

Ma *et al*. (2020) studied the distribution of bryophytes with respect to different soil condition in northeast China by using Redundancy analysis (RDA) and concluded that sodium and phosphorous content in soil as the main environmental factors affecting the distribution of bryophytes.

Sharma *et al*. (2021) studied the bryophytes of Panchase along the elevation range 1,648 m to 2,517 m and found 62 species in this region. The distribution of bryophytes was explored on two different slopes and top of the mountain and found more species in north- facing slopes. They also concluded that moist and shady places favors the luxuriant growth of bryophytes.

Literature review clarifies that the study of Nepalese bryophytes is just limited to exploration and documentation. But, the research of Sharma (2018) in Phulchoki hill, Kathmandu and Paudel (2019) in far western Nepal, included environmental variables (herb cover, canopy cover, elevation, bare ground, etc.) and soil parameters (moisture, p^H) along with bryofloristic exploration. As the soil macro-nutrient are found to show significant relation with the diversity in higher plants, which is lacking in case of Nepalese bryophytes. So, considering the above mentioned research gaps, the present study aimed to explore bryophytes of Central Nepal along with their ecology.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Study Area

3.1.1. Location

Palpa is a District of Central region of Nepal situated between 27˚ 34' - 27˚ 57' N latitude and 83˚ 15' - 84˚ 22' E longitude (Figure 1). It covers about 1366 sq km area among which 52.11% (711 sq km) is covered by forest (Mahato, 2014), 18% is of Chure region and remaining 82% in Mahabharat range (DFO, 2007). This study area covers both tropical and sub-tropical region i.e. 300- 1500masl (Dovan –Chahara). The study was done in an elevation gradient making 5 elevation bands.

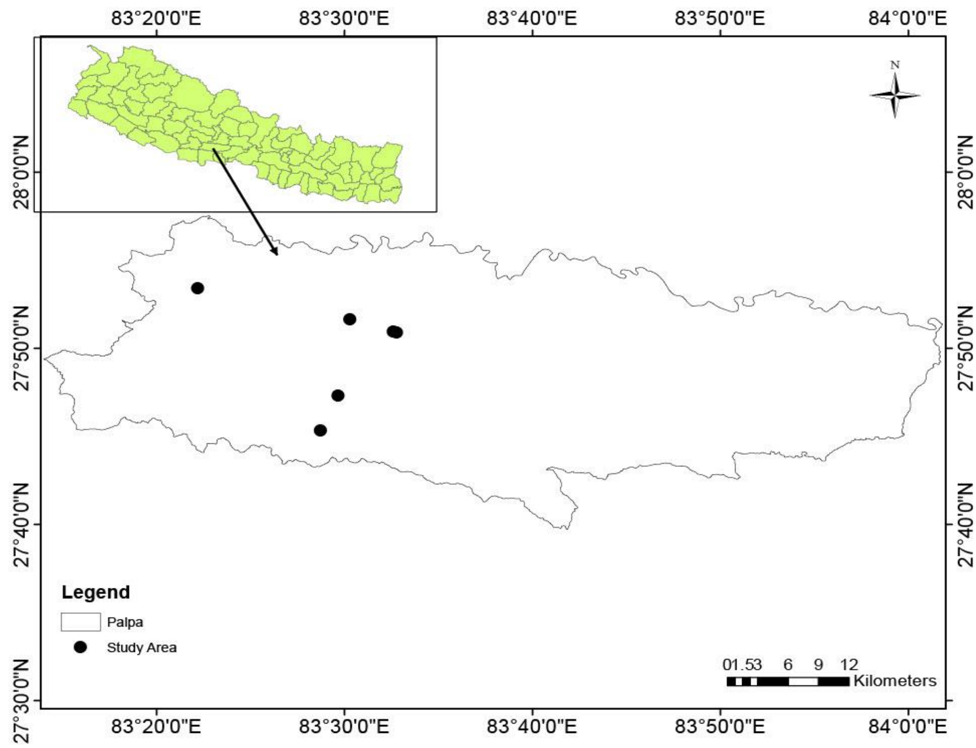

Figure 1: Map of Palpa District showing study area

3.1.2. Vegetation

More than half of the area of Palpa District is covered by forest i.e. 52.11% (71213 ha) among which Chure region covers 18% and 82% by Mahabharat range (Mahato, 2014; DFO, 2007). There is no uniformity in the forest type, the dominant forest type in the study area are: *Shorea robusta* forest and mixed hardwood forest at lower altitudes and *Pinus roxburghii* forest and *Schima-Castanopsis* forests at higher altitudes. Over 200 species of Non-Timber Forest Products (NTFPs) have been recorded from Palpa District (Bikaska Pailaharu, 2004). Some of the high-valued medicinal plants are also reported from Dovan Bottleneck Area (Shrestha *et al*., 2003; Aryal 2005). Bhandari (2006) reported 193 species of plants in a floristic study conducted in Dovan, Palpa. Most of the Non-Timber Forest Products (NTFPs) are collected from government and community managed forests, but *Cinnamomum tamala*, which is the most traded species in the area, is collected only from private forests. Especially the farmers and herdsman collect Non-Timber Forest Products (NTFPs) for trade and household use during their leisure time.

3.1.3. Climate

The climatic data was taken from meteorological station situated in Tansen Municipality of the study area. According to the meteorological data from 2010-2021 the climatic condition of the study area is tropical monsoon type where the summer are wet and winter are dry. There is no rainfall recorded in November, the maximum rainfall is recorded in July i.e. 516mm.The hottest days are experienced in June with the temperature variation between 18.75-30°C and this temperature goes on decreasing and lowest in January i.e. 6.22-19.45°C (Figure 2).

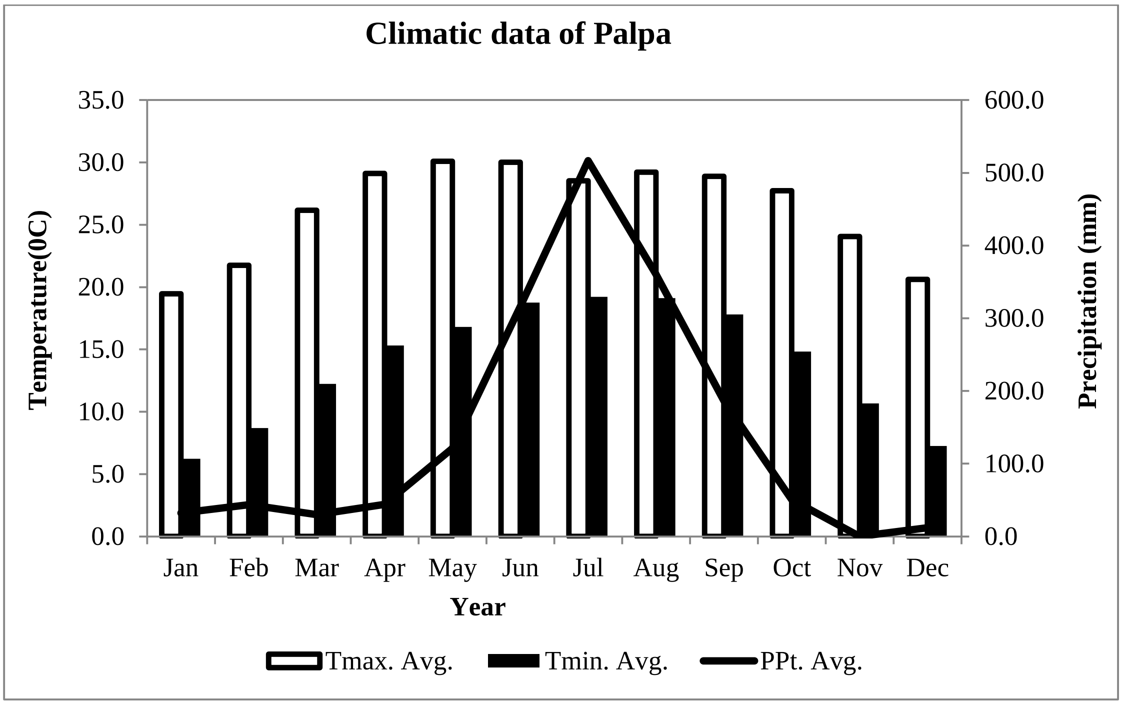

Figure 2: Minimum and Maximum average temperature (°C) and average precipitation of Palpa District from 2011-2021. Source: Department of Hydrology and Meteorology (DHM, 2022), Nagpokhari, Kathmandu, Nepal.

3.2. Methods

As the study was conducted in the lower elevation range, the best season for collection of bryophytes in this region was November to February (Pradhan, 2019). The field study was frequently carried out in this period i.e. from November, 2021- February, 2022. The present study required both qualitative and quantitative information, so the data collection was also done carefully along with the collection of the specimens. The quantitative data included species number and various environmental parameters whereas the qualitative data included distribution range, identification, etc.

3.2.1. Sampling design

The method of sampling and data collection was according to Paudel (2019) with few modifications. Sampling was done by systematic random sampling. Different habitats were sampled at an altitudinal range from 300-1500 masl and this altitude was divided into 5 bands at an interval of 300 ± 85 m depending upon the topography. The sampling plot was circular plot of 10 m radius (Hazell *et al*., 1998; Newmaster *et al*., 2005) with 5 mini-plot of 1m x 1m (Vanderpoorten *et al*., 2004; Mezaka *et al*., 2009) one plot at the center and 4 plots in 4 different directions at an 90°angle to avoid biasness (Figure 3). Repeated circular plot at the same elevational band was laid at a distance of atleast 50 m (Sun *et al*., 2013). The altitude was recorded by using Garmin's GPS. The soil sample was collected for nutrient analysis. And the various environmental variables such as elevation, canopy cover, bare ground cover, coverage of other plants, rock cover, etc. was noted and well analysed during the study.

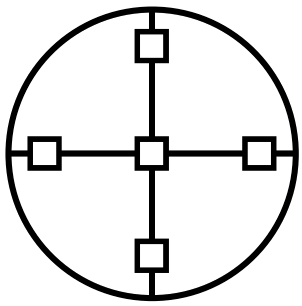

Figure 3: Sample plot (circular plot of 10 m radius with 5 rectangular mini-plots of 1x1m inside)

3.2.2. Sample Collection

The study was carried out in Palpa District following the route of Siddhartha highway from Dovan to Chhahara as the final destination point. The elevation range of this region was 300 - 1500 masl. The field visit was carried out frequently from November, 2021 to February, 2022 for both floristic composition of bryophytes and its diversity.

Now before the collection of the specimens from their habitat all the useful data was noted and the clear photograph was taken from the camera (Samsung A32 series version 13.0.01.21) and then collected. The collection of liverworts and hornworts was bit difficult without any tool as it was tightly attached to the substratum. So a sharp thin knife was used to detach the specimens. The collected specimens were then transferred to the plastic zipper bag to make them air tight in the field at the same time the labelling of the specimens was done which include the information like collection number, collection date, altitude, longitude, latitude, habitat, locality, etc. Then the collected specimes were washed thoroughly to remove the attached soil and this cleaned samples were transferred to paper pockets made up of newspaper which soaked up the moisture in the samples and make it fully dry which can be preserved for long time for future study.

3.2.3. Preservation

Dry preservation method was used for the preservation of the specimens. All the specimens were dried using the paper pockets made up of newspaper. After fully drying these specimens were transferred to the paper pockets measuring 10X 15cm made from the photocopy paper of standard size and were well labelled after the identification of each specimens.

3.2.4. Identification

The Identification of the common species was done in the field with the help of the hand lens. The identification of all the collected species were done on the basis of both morphological and anatomical characteristics. The morphological characters were observed in the stereomicroscope and for the anatomical characterization light microscope of 4X, 10X and 40X magnification was used.

The characterization of all the three types of bryophytes (liverwort, hornwort and mosses) was not same. Thalloid bryophytes were characterized on the basis of length, breadth, margin, anatomical differentiation of the internal tissues, scales (colour, position, arrangement), rhizoids and their types, presence of the air pores, arrangement of the air chambers, position of sporophytes, shape of the sporophyte, thickening of the spore wall, etc. In case of the leafy liverworts the arrangement of the leaves, internal tissues differentiaion, margin, colour, etc. were observed. In case of hornworts the characters such as length and breadth of thallus, margin the size of the sporophytes the colour of the spores their size arrangement and morphology of the spores and elaters, etc. were observed. As mosses were a bit larger in size compared to 2 other lineages so some of them were easily identified morphologically. The characterization of mosses was done on the basis of shape, size, apex and margin of the leaves; presence and absence of costa in leaves; shape of the basal, middle and the apical cells of the leaves, position, size and the colour of the seta; shape, length and breadth of the capsule; types of calyptra and peristome teeth; shape, size and colour of the spores, etc.

The characterized specimens were identified on the basis of the noted characters with the help of the standard literature such as Gangulee (1969-1980), Kashyap (1972) and Cases *et al*. (2009). Proper author citation was given to the specimens according to the data in TROPICOS. The identified species were classified following the classification of Stotler and Crandall-Stotler (2005) for hornworts, Crandall-Stotler *et al*. (2009) for liverworts; and Goffinet *et al*. (2009) for mosses. The voucher specimens were deposited at the Central Department of Botany, Tribhuvan University.

3.2.5. Labelling

Labelling contains important information on field data of herbarium specimens (Pradhan, 2008). The label of the specimens shows the information of the specimens and help the others to know the habitat, approprate time for the collection, altitude, etc. The format of label used in this study is as follows:

Bryoflora of Nepal	
Collection No.:	Date of collection:
Latin name:	
Common/ Vernacular name:	
Family:	
Locality:	District:
Altitude:	
Latitude	Longitude
Remarks:	
Collector(s):	
Determined by:	Date:

3.2.6. Species richness and environmental variable

The present study had two types of data i.e floristic and species richness.

The floristic data included the total number of species collected and examined in the laboratory by simply entering the data into the MS Excel and analysing it using the bar graph and pie charts to show the differences in number.

The different ecological data which consists of plot wise information of presence and absence of species in each plot was used to calculate species richness. Here the species richness is number of species in each plot.

Species richness = no. of species per plot (Ingerpuu and Sarv, 2015)

= count of different species.

Different environmental variables such as elevation range, bare ground, canopy cover, herb cover, ground cover by other plants were calculated for each sub-plot. The quantitative calculation of the environmental variables were in the scale between 0% to 100%. The relation was calculated by using Generalized linear Model by using PAST software version 4.03 (Hammer *et al*, 2001). Before analysing the data, the mean of 5 subplots of one circular plot was used in order to minimize the error.

3.2.7. Soil analysis

The soil was collected from different plots to determine Soil Organic matter, Nitrogen content, Phosphorous and Potassium by using different protocols. Besides this the elevation wise soil texture was also determined.

The methods used to analyse different soil parameter were as follows:

1. Organic matter by Walkey and Black method (Gupta, 2002; Broadbent, 2015).
2. Potash by Flame photometer (Thomos, 1982).
3. Phosphorous by Modified Olsen's bicarbonate method (Gupta, 2002).
4. Nitrogen derived by Kjeldahl method (Bremner, 1960)
5. Soil texture for each elevation by hydrometer method (Bouyoucos, 1962).

3.2.8. Data analysis

The data showing the distribution of bryophytes belonging to different groups (linaeages), class, order, family, genus was directly analysed with the help of MS-excel and interpreted by using bar-graph. The relationship between species richness pattern and different environmental variables was analysed by Generalized Linear Model (GLM) using PAST software version 4.03 (Hammer *et al,* 2001).

The analysis of the multiple environmental variable with the bryophyte species richness was done by using multivariate analysis or ordination. The environmental variables which was analysed against bryophytes species were elevation, bare ground, rock cover, canopy cover, herb cover, bryophytes cover, other plants, organic carbon, nitrogen content, phosphorous, potassium. For this, first of all indirect gradient analysis i.e Detrended Correspondance Analysis (DCA) was done by using R packages version 3.6.2 (R Core Team, 2019). As the DCA showed the axis length and Eigen value greater than 2.5 and 0.5 respectively, Canonical Correspondance Analysis (CCA) was performed.

CHAPTER FOUR: RESULTS

4.1. Floristic Composition and Distribution Pattern

4.1.1. Lineages of Bryophytes

During the field exploration of Palpa District, altogether 39 species of bryophytes belonging to 5 classes, 10 orders, 21 families and 27 genus were recorded. Among the 3 lineages mosses showed their dominancy in number of species i.e. 20 species which is 51% of the total recorded species belonging to 13 genera, 10 families, 6 orders and 2 classes followed by liverworts i.e. 16 species (41%) belongining to 12 genera, 10 families, 3 orders and 2 classes; and least number were of hornworts i.e. 3 species (8%) belonging to 2 genera, 1 family, 1 order and 1 class (Figure 4).

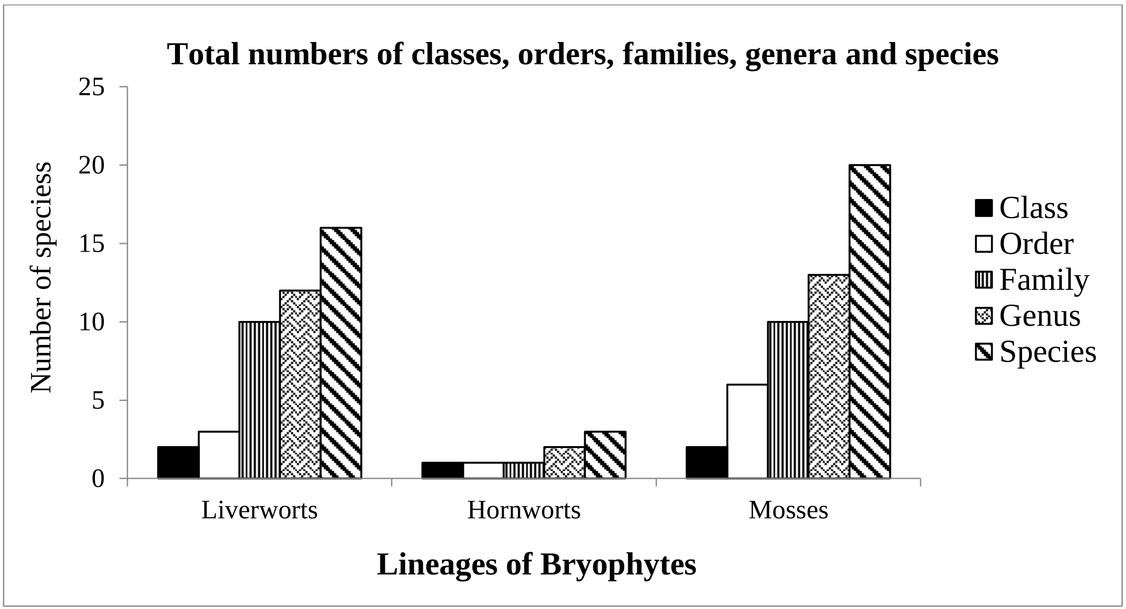

Figure 4: Total number of classes, order, families, genus and species within different lineages.

4.1.2. Classes of Bryophytes

Among the 5 recorded classes of bryophytes, bryopsida was dominant with 16 species (41%) belonging to 10 genera, 9 families, and 5 orders. The class bryopsida was followed by Marchantiopsida with 10 species (26%) (7 genera, 5 families, and 1 order), Jungermaniopsida with 6 species (15%) (5 genera, 5 families, 2 orders), Polytrichopsida with 4 species (10%) (3 genera, 1 family, 1 order) and least was of Anthocerotopsida with 3 species which is (8%) of total species belonging to 2 genera, 1 family and 1 order (Figure 5).

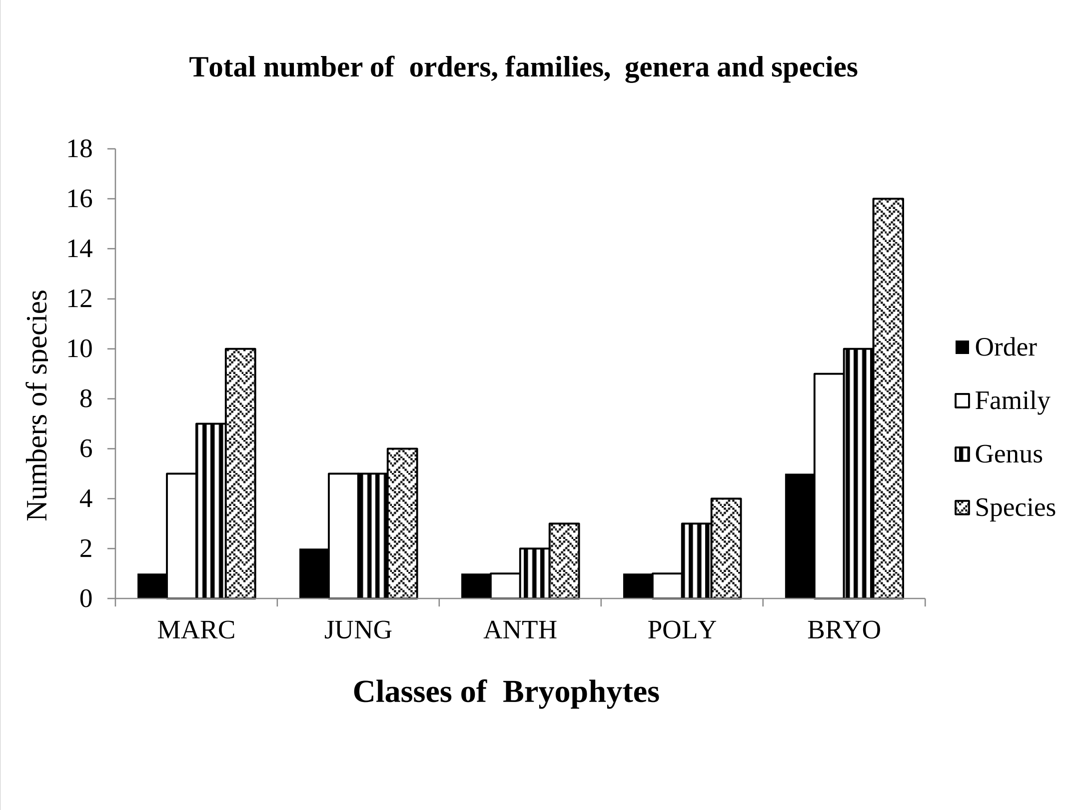

Figure 5: Total number of order, families, genus and species within different classes.
MARC: Marchantiopsida, JUNG: Jungerminopsida, ANTH: Anthocerotopsida, POLY: Polytrichopsida, BRYO: Bryopsida

4.1.3. Orders of Bryophytes

Among the 10 recorded orders the dominant order was Marchantiales with 10 species (26%) belonging to 7 genera and 5 families followed by Dicranales with 7 species (18%) (3 genera and 3 families), Jungermanniales with 5 species i.e. 13% (4 genera and 4 families), Polytrichales with 4 species i.e. 10% (3 genera and 1 family), Anthocerotales with 3 species i.e. 8% (2 genera and 1 family), Bryales (2 species, 1 genera and 1 family), Bartramiales (2 species, 1 genera and 1 family), Pottiales (2 species, 2 genera and 1 family), Hypnales (2 species, 2 genera and 2 families) i.e 5% , Funariales and Porrellales with 1 species belonging to 1 genera and 1 family (Figure 6).

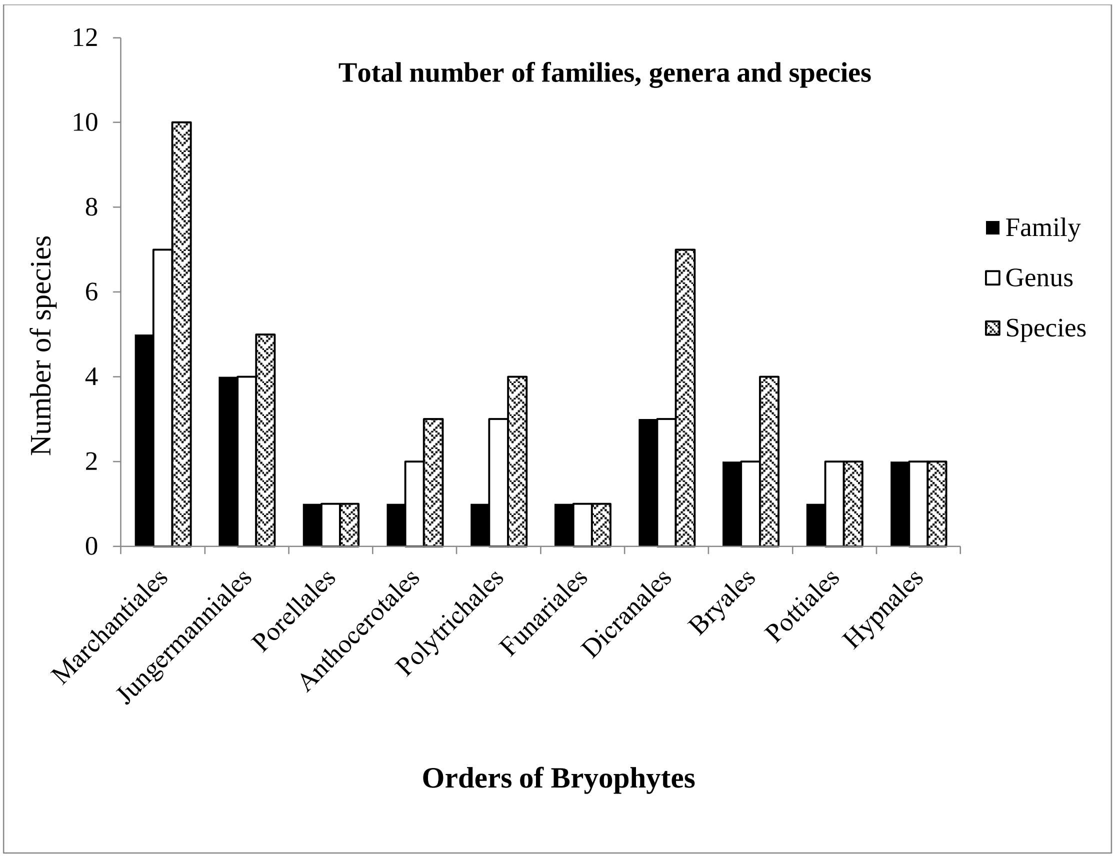

Figure 6: Total number of families, genus and species within different orders.

4.1.4. Families of Bryophytes

Among the 21 recorded families of bryophytes, both linages liverworts and Mosses showed equal dominancy in number of families i.e. 10, and hornworts were represented by single family. Among these families, Aytoniaceae showed dominacy with 5 species belonging to 3 genera followed by Polytrichaceae (3 genera and 4 species), Fissidentaceae (1 genera and 4 species), Anthocerotaceae (2 genera and 3 species), Pottiaceae (2 genera and 2 species), Bartramiaceae, Bryaceae, Dicranaceae, Lophocoleaceae and Marchantiaceae (1 genera and 2 species). Remaining families i.e Coenocephalaceae, Dumortieraceae, Monosoleniaceae, Jungermanniaceae, Lejeuneaceae, Gymnomitriaceae, Scapaniaceae, Funariaceae, Bruchiaceae, Meteroriaceae, Brachytheciaceae comprised 1 genera and 1 species (Figure 7).

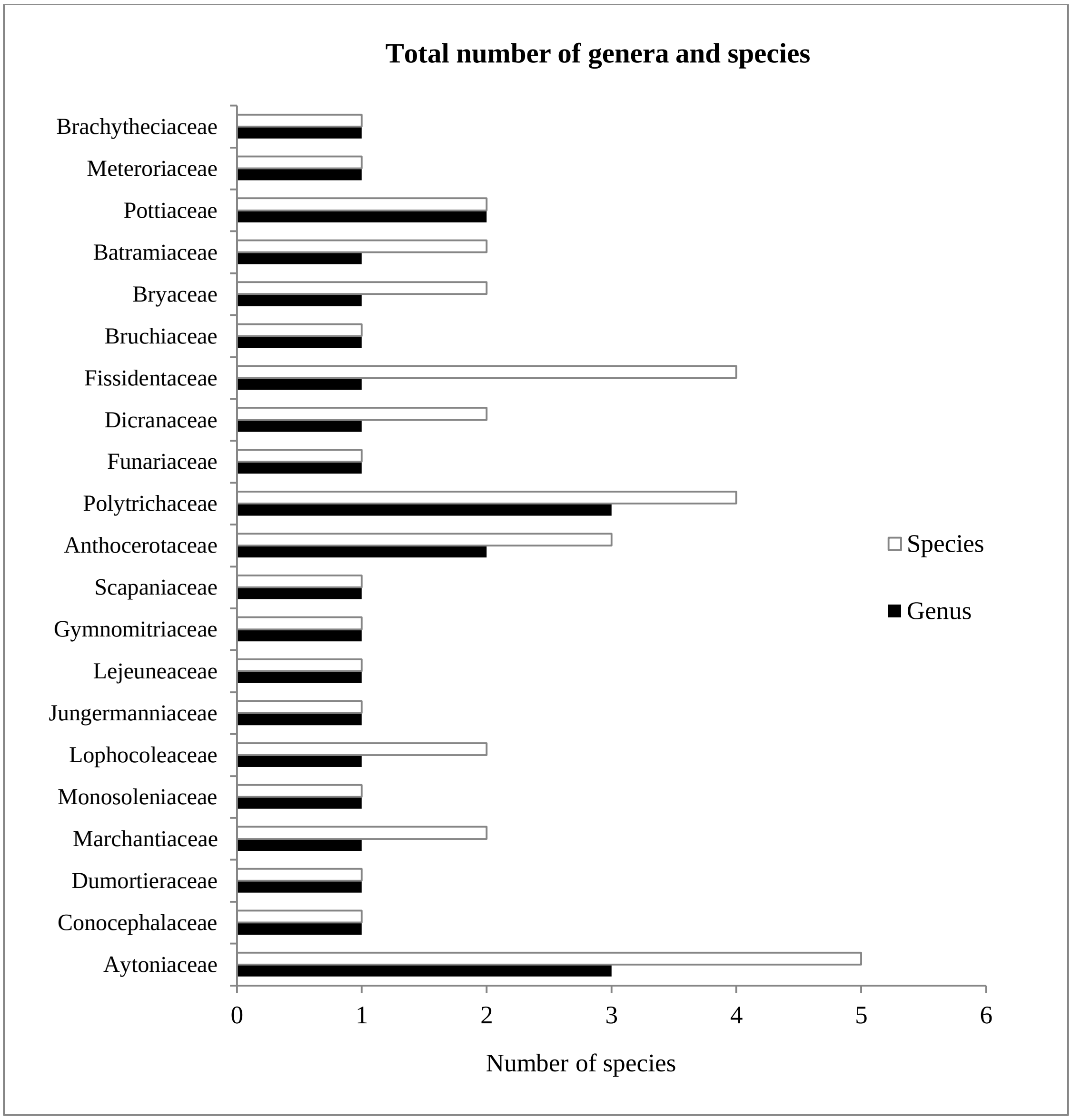

Figure 7: Total number of genus and species within different families.

4.1.5. Genera of Bryophytes

Among the 27 genera, *Fissiden* was the dominant with 4 species followed by *Asterella* (3 species); *Marchantia, Heteroscyphus, Anthoceros, Pogonatum, Dicranum, Bryum* and *Philonotis* (2 species). Remaining genera *Coenocephalum, Dumortiera, Monosolenium, Plagiochasma, Reboulia, Jungermannia, Lejeunea, Nardia, Scapania, Folioceros, Atrichum* (1 variety), *Polytrichum, Funaria, Trematodon, Hyophila, Bryoerythrophyllum, Meteriopsis and Eurhynchium* represent 1 species each (Figure 8).

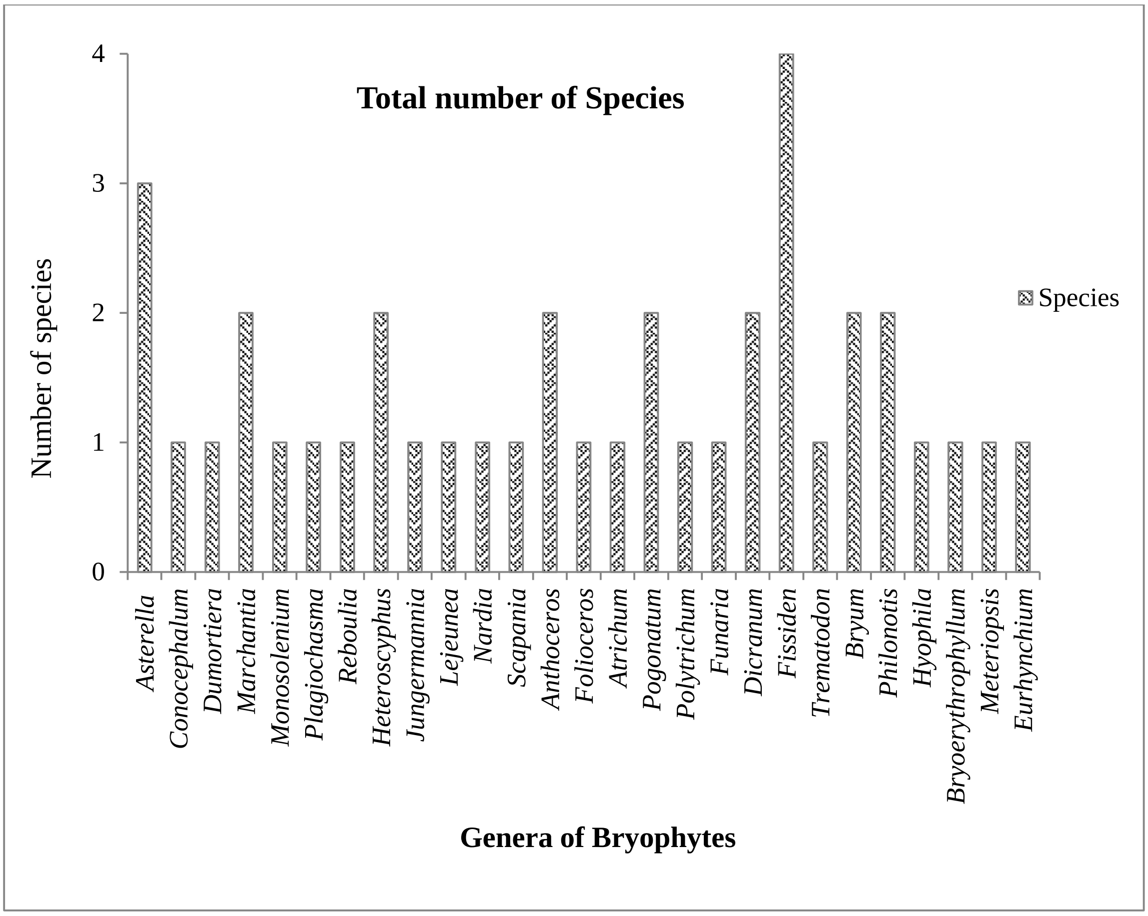

Figure 8: Total number of species in different genera.

4.1.6. Habitat wise distribution of bryophytes

Among the documented 39 species of bryophytes more than half of the species were distributed in terrestrial habitat with 22 species (56%) followed by species distributed in both rocks (lithophytes) and terrestrial habitat with 12 species (31%), epiphytes with 3 species (8%) and lithophytic habitat with only 2 species (5%) (Figure 9).

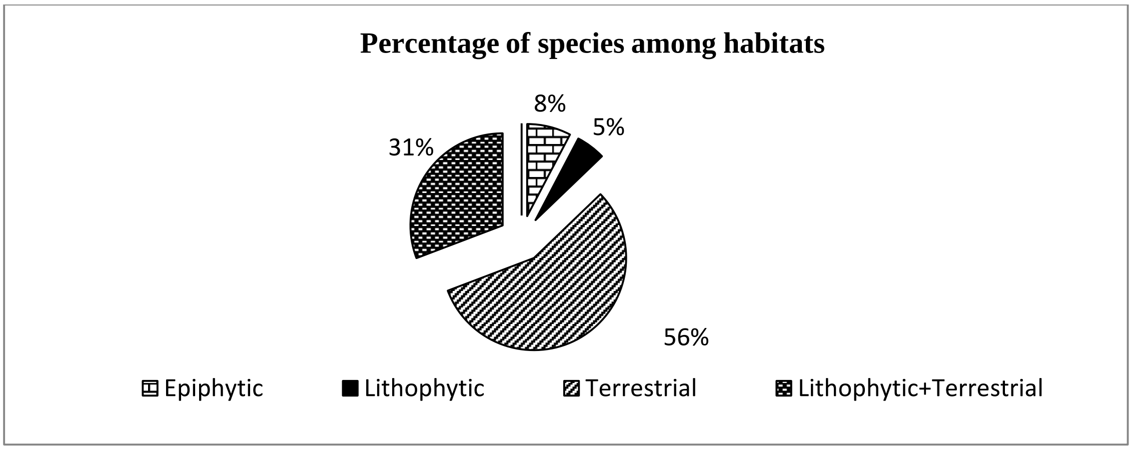

Figure 9: Habitat wise distribution of bryophytes

4.2. Soil characteristics

In the present study, the percentage range of Carbon and Nitrogen shows a increasing trend till 900 m elevation above 900 m i.e. 1200 m and 1500 m shows decreasing trend with incresing elevation 1500 m showing the lowest range. In case of Phosphorous content the range goes on decreasing from 300 m-900 m and highest range was observed in 1200 m elevation which decreases rapidly at 1500 m with lowest range of Phosphorous content. Unlike other soil parameters (Organic Carbon, Phosphorous and Nitrogen) Potassium content didn't followed the increasing or decreasing trend the range was random with lowest range observed in 1500 m. The soil texture was clayey loam from 300m- 600m, loamy at 900-1200m and loamy sand at 1500m elevation (Appendix 7).

4.3. Bryophytes species richness with different environment variables

The Pearson's correlation matrix was made for the varoius environmental factors along with the overall species richness and all the three different lineages of bryophytes. The matrix showing the correlation between environmental variables and species richness (Appendix 8).

4.3.1. Relatioship between species richness and their elevational range

The regression analysis showed statistically significant inclining linear relation between species richness and elevational range (r^2=0.62064, p=0.0001). The number of species increases with the increasing elevation (Figure 10).

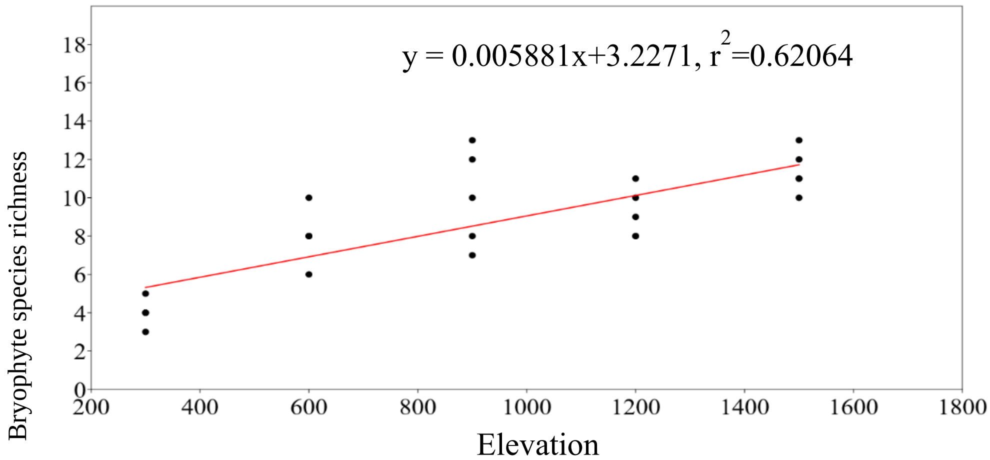

Figure 10: Relatioship between species richness of bryophytes and their elevational range. The fitted line indicate the Generalized Linear model (GLM) first order.

4.3.2. Relatioship between species richness and bare ground

The regression analysis showed statistically significant declining linear relation between species richness and bare ground (r^2=0.36018, p=0.0013). The number of species decreases with the increase in the open space (Figure 11).

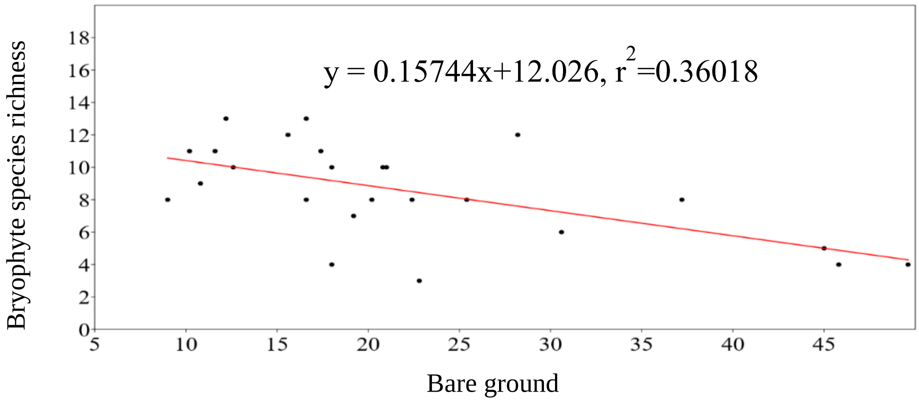

Figure 11: Relatioship between species richness of bryophytes and bare ground. The fitted line indicate the Generalized Linear model (GLM) first order

4.3.3. Relatioship between species richness and canopy cover

The regression analysis showed statistically significant declining linear relation between species richness and Canopy cover (r^2=0.80687, p=0.0001). The number of species decreases with the increase in the open space (Figure 12).

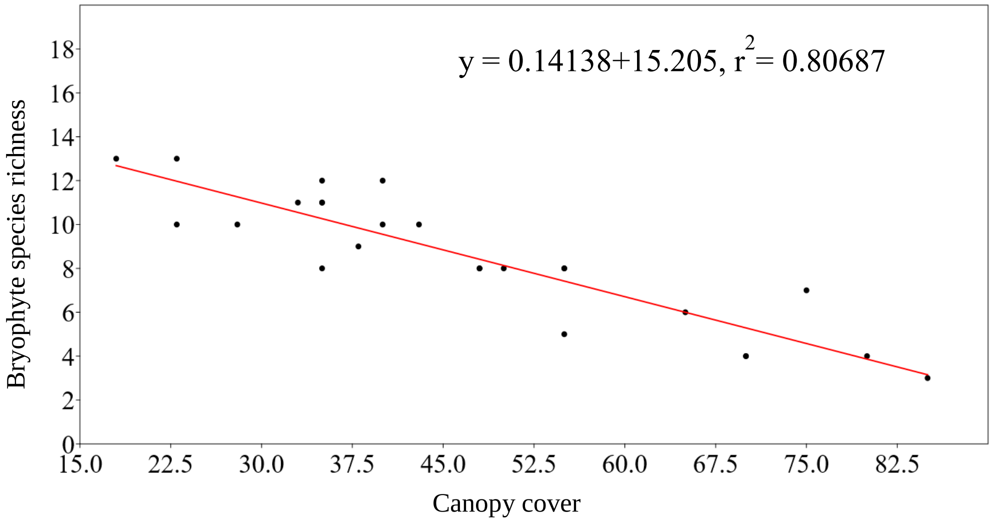

Figure 12: Relatioship between species richness of bryophytes and Canopy cover. The fitted line indicate the Generalized Linear model (GLM) first order.

4.3.4. Relatioship between species richness and other environmental variables

The relation between bryophytes species richness was statistically insignificant with rock cover (p =0.18142), other plant (p = 0.098884) and herb cover (p = 0.87693) (Appendix 8).

4.3.5. Relatioship between species richness and soil variables

The relation between bryophytes species richness was statistically insignificant with soil organic carbon (p =0.4423), soil nitrogen (p =0.4308), Phosphorous (p =0.8648), Potassium (p =0.2663). The relation was also similar to all the lineages but the relation of mosses and potassium was statistically significant with p-value=0.0497 (Appendix 8).

4.4. Species composition with different environmental variables

Multivariate analysis (Ordination) was used to show the relation among the species composition and environmental variables. The data containing presence absence table of the bryophytes along with the elevational band was treated with the DCA analysis (Table 1). The analysis showed that the eigen value (Variance) was in a decreasing order from DCA1 to DCA4. The eigen value for DCA1 to DCA4 was 59%, 30%, 23%, and 18% respectively which showed high heterogenity in the habitat. The axis length (gradient length) was 3.97 SD units which was also in the decreasing order which indicates high β diversity among the plots. As the eigen value was greater than 0.5 and and also the axis length was greater than 2.5 SD unit which suggests Canonical Correspondance Analysis (CCA) for further which would show the relation between multiple environmental variables and bryophytes species composition.

Table 1: Summary of DCA

	DCA1	DCA2	DCA3	DCA4
Eigen values	0.59	0.30	0.23	0.18
Decorana value	0.59	0.28	0.16	0.09
Axis length	3.97	3.29	2.10	1.81

The result obtained from CCA plot show that elevation as the most significant gradient which was indicated by the CCA first axis (Figure 13). All the environmental variables varied significantly with the bryophytes species composition such as elevation, bare ground, herb cover, bryophyte cover, rock cover, canopy cover, other plant, soil carbon, nitrogen, Phosphorous, Potassium. Strong and positive correlation was shown between Soil carbon, Nitrogen, bryophyte cover and Pottasium, whereas they showed negative correlation with elevational gradient. Other plant cover and phosphorous content showed strongly negative correlation between each other. On the other hand rock cover, herb cover, canopy cover, bare ground showed negative correlation between phosphorous content and other plant cover.

Bryophyte species such as *Dicranum himalayanum*, *Eurhynchium praelongum, Meteriopsis reclinata*, *Philonotis thwaitesii*, *Anthoceros punctatus*, *Anthoceros* sp., *Bryum* sp., *Pogonatum microstomum*, *Lejeunea* sp., *Bryum caespiticum*, *Atrichum undulatum* var. *subserratum*, showed high abundance at high elevational gradient where as low abundance at the lower elevational band, nitrogen and carbon rich soil, bryophytes cover and potassium rich soil.

Coenocephalum conicum, Marchantia polymorpha were nitrogen and carbon loving species. *Monosolenium tenurum* and *Bryoerythrophyllum dentatum* were bare ground loving species found within low elevation and canopy rich environment in association with other bryophyte species. Besides this *Pogonatum submacrophylum, Dumortiera hirsuta*, *Dicranum setchwanium* were also found in association with various other bryophyte species in lower elevation. *Fissidens* sp., *Funaria hydrometrica* and *Folioceros assamicus* were phosphorous loving species. *Marchantia emarginata* and *polytrichum commune* were potassium loving species. *Fissidens sylvaticus, F. taxifolius* and *Asterella multiflora* were favoured by herb cover. Similarly, *Heteroscyphus planus, H. argutus, Fissidens bryoides* and *Hyophila involuta* were favoured by rock cover (Figure 13).

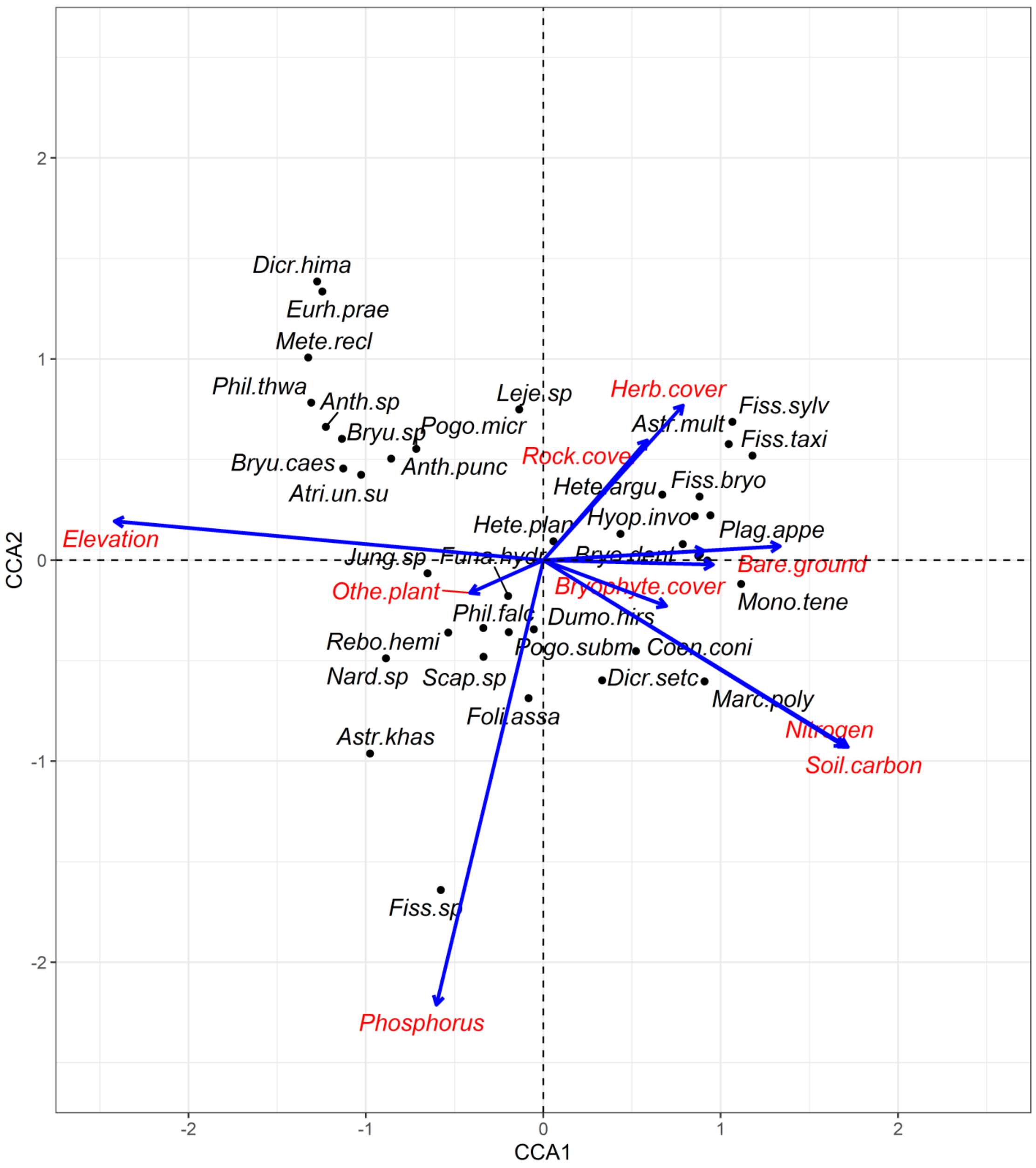

Figure 13: CCA triplot. The arrows represents the environmental variables with the species name in abbreviated form.

CHAPTER FIVE: DISCUSSION

5.1. Floristic composition of bryophytes

Floristic composition documents the plant communities along with abiotic factors of a particular geographical region. Such studies are very beneficial in order to find out the different patterns of plants species. Nepal has diversified topographical regions which supports rich floral and faunal diversity despite of its small size. In bryofloral diversity also it holds about 5% of the world's species i.e. 1217 species (Pradhan, 2020), among which 31 species are endemic (Joshi and Joshi, 1991). The present study explored the diversity of bryophytes and documented altogether 39 species.

Worldwide distribution pattern of three lineages of bryophyte shows dominancy of mosses followed by liverworts and then hornworts (Asakawa *et al*, 2013). The similar distribution pattern has been noticed in adjoining countries like China (Song *et al.*, 2021), Bangladesh (https://en.banglapedia.org), different regions of India like Odisha (Mishra *et al.*, 2016), Uttarakhand (Asthana and Sahu, 2013; Sahu and Asthana, 2015), Western ghats of Karnataka (Aruna and Krishnappa, 2014). The present study shows high dominancy of mosses among the three lineages which is similar to the overall pattern bryophyte distribution in Nepal (Pradhan, 2020). The conclusion derived from Gradstein (2011) seems appropriate explanation for the proportional distribution of three lineages of bryophytes. Accordingly, the dominancy of mosses and liverworts is favored by their capacity to grow on variety of habitats (rocks, crevices of rocks, tree trunk, soil, etc.); mosses can grow even in drier conditions, and hornworts are very selective and can grow in much moist condition.

Among the classes, the present study shows high dominancy of Bryopsida which was similar to the previous study of almost similar elevation carried out in western Nepal by Paudel (2019). Besides, some similar studies carried out in various region of the country in the higher elevation by Sharma (2018), Karki and Ghimire (2019), Sharma *et al*. (2021) also showed high dominancy of members of bryopsida. The studies in India by Alam *et al.* (2012) also showed the similar result.

The class Bryopsida was followed by Marchantiopsida, Jungermaniopsida, Polytrichopsida and Anthocerotopsida. Contrast results were obtained from previous research by Paudel (2019), where the class Bryopsida was followed by

Marchantiopsida, Jungermaniopsida, Anthocerotopsida and Polytrichopsida. Despite of the similarity in the elevation between the present work and previous study done by Paudel (2019) the differences in the result may be due to lacking of proper habitat for Anthocerotopsida in present study area which prefers moist terrestrial habitat and higher number of species in Polytrichopsida suggest their ability to grow on rocky and disturbed habitat. Khati (2021) also concluded that Polytrichopsida can tolerate disturbance which resulted in the increasing number of species. The similarity between these 3 classes may be due to similar geographical condition for the growth of the species, and differences may be due to the habitat specificity of those species.

5.1.1. Class Marchantiopsida

Marchantiopsida consists of a single order Marchantiales which consists of 5 families. The high dominancy of order Marchantiales might be due to the most diverse habitat as they were found in damp and moist soil, rocks forming a mat of a single species or associated with different herbs, pteridophytes or with other bryophytes specially mosses. *Marchantia* is the only genus under Marchantiaceae with 2 species *M. emarginata* (300-900 m) and *M. polymorpha* (600 m).Pradhan (2008) reported these two species as the most common species of the lowlands. Paudel (2019) reported *M. emarginata* only from lowland in an elevation 176-182 m but it was also reported by Sharma (2018), and Karki and Ghimire (2019) at 1513 m and 1643 m respectively. Besides this Pocs and Ninh (2005) who suggested *M. emarginata* as the Southeast Asian taxon. *M. polymorpha* was not that dominant in the present study though many studies in Nepal (Paudel, 2019; Sharma, 2018)and in the adjoining countries like India shows the distribution range between 700-2100 m (Alam *et al*, 2012; Rashid *et al*, 2012).

Among the order Marchantiales, Aytoniaceae was the dominant family with 5 species. *Plagiochasma appendiculatum* was the most common species found under this family and has wide distribution range which was also reported by various Indian bryologist from 138- 2500 m altitude (Alam *et al.*,2012; Sahu and Asthana, 2015). Other species such as *Asterella* comprises 3 species (*A. khasyana*, *A. multiflora*, *A. wallichiana*) was also reported by Paudel (2019) and Pradhan (2008) in lowlands. But *A. mussuriensis* which was reported in central and eastern Nepal was not found in this study and similar result was also obtained in study in western Nepal by Paudel (2019). This suggests that *A. mussuriensis* is not found in drier geographical region or this may be due to lack of specified habitat for the species to grow. *Reboulia hemisphaerica* is also the genus that was reported in the present study under this family from 600-1500 m. Pradhan (2008) also reported this species in all three geographical regions from an elevation 355-1000 m. Similarly, Paudel (2019) reported this species from 1384 m.

An interesting plant species *Monosolenium tenerum* was found in this study in an elevation range of 325-600 m. It has high commercial value as it is used as an aquarium plant. This species was lacking in Paudel (2019). This was first reported by Pradhan *et al.* (2007) as new species from Bardia, Western Nepal and also listed it as rare species in an altitude of 180 m. Pradhan *et al.* (2007) also reported that the species was found in moist and shady place as it was found near the water sources in shady region.

Conocephalaceae consists of a single genus in this study i.e. *Conocephalum conicum.* This is the most common species under the family Conocephalaceae and was found to be distributed from an elevation 572 m-1586 m in the present study. But, Paudel (2019) reported this species from 1342 m. The presence of species only in subtropical region may be related to the moisture content. Iqbal *et al.* (2011), Negi and Chaturvedi (2021) also reported the distribution of the species within this elevation range in India.

Dumortiera hirsuta was a single genus found from the Dumortieraceae family and was found from the lower elevation i.e. 286m -1560m elevation. Similarly, Pradhan (2008) reported this species from all three geographical region at an elevation 370-1000 m and Paudel (2019) reported this from 180m elevation. Pippo and Koponen (2013) also reported *Dumortiera* from similar elevation range (273-1580 masl) in China. Pocs and Ninh (2005) reported *Dumortiera* as Southeast Asian and Oceanic species. This indicates that *D. hirsuta* was found from the eastern to western region and has high distribution range despite the change in the rainfall pattern and different topographical features.

5.1.2. Class Jungermanniopsida

Jungermanniopsida consists of 4 families with 5 species. Lophocoleaceae consists of 2 species of *Heteroscyphus* (*H. argutus* and *H. planus). H. argutus* is common species found from eastern to western region of Nepal (Pradhan, 2008). Pocs and Ninh (2005) reported this species as Indomalesian Pacific species. *H. planus* was the new species recorded from Nepal in low land Terai (Pradhan, 2008). *Scapania* was found in the moist rocks in the present study from 300-1500 m but it was found in the same habitat at 1582 m by Paudel (2019). Sharma *et al.* (2021) suggested that the members of Jungermanniopsida was found in moist and shady places which was similar to the present study as most of the species of this class were recorded from the moist habitat.

5.1.3. Class Polytrichopsida

Polytrichopsida consists of a single order Polytrichales is phylogenetically isolated lineages which consists of 436 species belonging to 23 genera (Buck and Goffinet, 2000). The species of Polytrichopsida are found in siliceous or acidic substrata forming compact tall trufts of closely packed upright shoots (Uniyal, 2004). In present study the class Polytrichopsida consists of only 4 species belonging to 3 genera i.e. *Pogonatum, Polytrichum* and *Atrichum*. These species were found to be making a compact tufts in the present study. Paudel (2019) found lower diversity of the species in western Nepal within the same elevation range. Khati (2021) suggested the high diversity of the members of this class in disturbed habitat. So this may also be the reason for the high diversity of the Polytrichopsida as compared to Paudel (2019) as various infrastructure development works has been continuously been carried out in the present study area which creates disturbances in the natural habitat.

5.1.4. Class Bryopsida

Bryopsida is the most dominant class among the 5 classes of bryophytes. Among this, the family Fissidentaceae shows its dominancy under Dicranales order. Four species are reported under a monotypic genus *Fissidens.* The elevation gradient of the genus was 300-1200 m in the present study. This monotypic genus comprises about 900 species (Imura and Iwatsuki, 1988; Ishihara and Iwatsuki, 1992), among which Nepal consists of 49 species (Pradhan, 2000 a). Among the 4 *Fissidens* species 3 were found in tropical region i.e. *F. taxifolious, F. sylvaticus* and *F. bryoides*. One species of *Fissidens* was found in sub-tropical region. *F. bryoides* was distinguished by its smaller size among the 4 species. *F. taxifolious* showed their distribution in various habitat such as epiphytes, lithophytes and terrestrial but the habitat in present study was only limited to terrestrial habitat. Besides Fissidentaceae there are 2 more families under this order i.e. Dicranaceae and Bruchiaceae. Dicranaceae consists of 2 species *Dicranum schwanium* and *D.himalayanum. D. setchwanium* is found in both tropical and sub-tropical band but *D. himalayanum* was only found in highest elevations of the study area i.e. above 1480 m. This suggest that *D. himalayanum* are not distributed to tropical region which may be due to higher temperature in tropical band or lack of specific habitat. Another family Bruchiaceae consists of only one species i.e. *Trematodon longicollis* that is only reported in the tropical band or lower elevation but, it was reported from Sub-tropical band by Paudel (2019). Similar elevation range for the species was suggested by Mitten (1859) in Assam, India. Pradhan, 2008 also reported this species from eastern and central Nepal. The contrast result by Paudel (2019) may be due to drier soil condition in the tropical band.

Funariaceae consists of 303 species worldwide under 13 genera (Xu and Chang, 2017). In this study only one species of Funariaceae was found (*Funaria hygrometrica*) in both tropical and subtropical region, this may be due to high dispersal capacity as also been suggested by Govindapyari *et al.* (2010).

Bryales is an order of bryopsida which consists of single family in the present study i.e. Bryaceae. Bryaceae is the largest and widespread family which consists of genera with taxonomic difficulties. Nepal consists of 82 species belonging to 7 genera of Bryaceae (Pradhan and Joshi, 2008). Only 2 species were reported in present study i.e. *Bryum* sp. and *Bryum caespiticum*. Both *Bryum* sp. and *B. caespiticum* were collected from sub-tropical band, but it showed wide range of distribution in previous study by Pradhan and Joshi (2008) in both Tropical and Sub- tropical band from 300-4800 m in Central Nepal. Some species of *Bryum* i.e. *Bryum capillare, Bryum argenteum* showed survival with luxuriant growth in polluted environment (Govindapyari *et al.*, 2010).

Batramiaceae is another Family of order Bartramiales which also consists of 2 species of *Philonotis* i.e. *P. falcata* and *P. thwaitesii. P. falacata* was found at an elevation range from 572 m- 1586 m which was in the similar elevation range reported by Pradhan (2015) from Sindhupalchowk. But contrasting result was found for another species *P. thwaitesii* as it was found in both tropical and sub-tropical region 950 m-1220 m (Pradhan, 2015) but found only in sub-tropical band in the present study area

1470-1586 m. The reason behind this may be the difference in moisture content of the soil of Palpa which lies towards western part from Sindhupalchok.

Pottiales is another order of Bryopsida which consists of only one family Pottiaceae with 2 species i.e. *Hyophila involuta* and *Bryoerythrophyllum dentatum* in the present study. *Hyophila involuta* was found in 635 m- 1140 m altitude which was similar to the elevation range reported by Pradhan (2008) and Pradhan (2015) from different lowlands of Terai region and South- eastern part of Sindhupalchowk of Central Nepal (200-1000 m). Similarly, Paudel (2019) also reported *Hyophila involuta* from the same elevation. *Bryoerythrophyllum dentatum* was widely distributed along the study area and was found in an association with other herb species or with various liverworts species in damp and moist places.

Hypnales order also consists of two families i.e. Meteroriaceae and Brachytheciaceae with one species each. *Meteriopsis reclinata* was reported as very common species from Himalayas and India to Celebes, an island in Indonesia. In Nepal it is reported in various collections from various authors such as Noguchi *et al.* (1966) and Noguchi and Iwatsuki (1975). It was also restricted in lower elevation in the present study and found in sub-tropical band as an epiphyte on the tree trunk which was similar to the habitat suggested by Karczmarz (1981). *Eurhynchium praelongum* of Brachytheciaceae was found on the upper elevation of the study area as an epiphyte and was not found in lower elevation range. This may be due to lack of proper habitat in the lower elevation as it is mostly found in damp and humid places on rotten logs or tree trunks.

5.1.5. Class Anthocerotopsida

Anthoceroptopsida is the class with lowest number of species in the study area i.e. only 3 species. The number of hornworts is comparably lower in regional study as well as worldwide. In the present study *Foliocerus assamicus* was found between 600 m and 1500 m. *Anthoceros punctatus* was found between 900 m and 1500 m and *Anthoceros* species was found in an elevation of 1500 m. *F. assamicus* was found as a new record by Pradhan and Joshi (2007b) from Central Nepal at 600 m, *A. punctatus* was recorded at 200 m -1250 m (Pradhan, 2008). All the 3 species were collected in terrestrial soil.

5.2. Species richness of bryophytes along elevation gradient

There are multiple environmental factors such as climate, elevation, slope, depth of litter, vegetation type, soil pH and soil Eh (redox potential), that affect the availability of the species, richness, composition, diversity, and also govern their ability for the luxuriant growth (Sun *et al*., 2013).

Past studies showed the hump shaped distribution curve for the bryophyte species with increasing elevation gradient in Nepal (Grau *et al*., 2007). The highest richness was observed at the temperate region (Pradhan, 2014b). However, the highest richness for liverworts was found at 2800 m altitude and 2500 m for mosses and the richness of bryophytes above temperate zone was found to be decreased (Grau *et al*, 2007). Current study on the bryophytes was carried out in tropical and sub-tropical band so the species richness curve was supposed to be linear because of the constrained elevation gradient. The present study showed high species richness at higher elevation range and thus follows the Rapoport's elevation rule. The species richness for mosses and hornworts showed significant inclining linear relation and the significance was more for the mosses. This finding was similar to that of Gradstein (2011) for mosses but liverwort didn't showed statistically significant relation which may be due to relatively short elevation gradient. The increasing richness of hornworts with respect to elevation may be due to their nature to grow on moist soil as moisture content is little bit higher at the higher elevation of the study area.

5.3. Bryophytes species richness with various environmental variables

The multivariate analysis of the species composition and various environmental conditions by using CCA showed that the distribution of the species is not favored by a single environmental condition but is influenced by the various biotic and abiotic factors in the habitat. The CCA plot showed that the species such as *Dicranum himalayanum*, *Eurhynchium praelongum*, *Meteriopsis reclinata*, *Philonotis thwaitesii*, *Anthoceros punctatus*, *Anthoceros* sp., *Bryum* sp., *Pogonatum microstomum*, *Lejeunea* sp., *Bryum caespiticum*, *Atrichum undulatum* var. *subserratum* were more significant with the elevation.

The CCA plot showed that most of the moss species were confined to and highly distributed to higher elevation range which was explained by the high adaptive nature of the mosses to be distributed in the harsh environment conditions. The result was similar to Gradstein (2011), who suggested the ability of mosses to grow on diverse habitat which increases the richness of mosses. The high diversity of the species in high elevation may be due to the loamy sand soil texture at high elevation which favors the growth of bryophytes. Similar result was reported by Vanderpoorten and Engels (2002). *Funaria hygrometrica* is the common species which was found in both rocky and terrestrial habitat was common in almost all elevation range near disturbed areas near roadsides and also in open canopy covered areas and CCA plot showed its close relation with the Phosphorous content in soil. Similar findings was suggested by Hoffman (1966), Southorn (1977) that greater abundances of *F. hygrometrica* inside the forest floor with litter canopy cover at higher elevation may be due to high concentration of Calcium, Potassium, Nitrogen and Phosphorous.

The Regression analysis showed significant but declining relationship with bare ground which means the richness increases with the decrease in bare ground. The reason may be scarcity of moisture and required microhabitats in the bare land for the growth of bryophytes species. The species which can tolerate the drought and harsh environmental conditions may be the reason for the decrease in the diversity. There was no significant relationship between the richness of bryophytes and rock cover, grass cover and with other plant species which showed contrasting result with Pharo *et al.*(2005) in which they found consistent declining relation with the grass cover. This may be due to the varied habitats and the various environmental conditions which hinders the proper statistical relation with the species richness. Other reason may be due to high canopy cover in the dense forest which hinders even the required amount of sunlight and other essential components for the growth of bryophytes and other vegetation in that land. This was similar with the result reported by Fenton and Frego (2005).

The species richness of bryophytes showed linear declining relation with canopy which means the species richness is mostly low at the area with high canopy cover. Canopy cover is reported as the best predictor for the distribution of bryophytes (Pharo and Vitt, 2000; Vanderpoorten and Engels, 2002). This finding was also similar to Fenton and Frego (2005) who suggested that remnant canopy favor high bryophytes diversity than open and clear canopy. The relation was also similar for liverworts and mosses but was insignificant for that of hornworts. This may be due to limited habitat for hornworts.

All the soil variables (N, P, K and OM) showed insignificant relation with overall bryophyte species richness but mosses showed significant linear declining relationship with potassium. This insignificance may be because there might be other soil parameters which might be contributing the diversity along with other soil properties. But, Ma *et al.* (2020) and Bergamini and Pauli (2001) suggest the significant relation with soil macro-nutrients. So, other soil parameters may also be the regions for the variations in results.

The total number of species reported in this study is comparatively very low as compared to Paudel (2019) who reported 89 bryophytes species in the same elevation gradient in far western Nepal. The reasons for the low number of species may be the lack of suitable environmental parameters. Palpa is a district with high rate of landslides which can easily sweep the vegetation. Additionally, road construction in the study area also cause the degradation of habitat.

Bryophytes mostly grow in the degraded landmass where they create favorable environment for other vegetation but the excessive rainfall in present study area erodes the bryophytes along with soil. Not only in monsoon but the problem of landslides are also observed in dry seasons which may be due to the less ability of soil particles to get bind. During field work at lower elevation, most of the places were found with negligible amount of soil on rock substratum. And the places with abundant soil were found to contain higher proportion of sand. These features along with rain water ultimately supports maximum surface runoff, thus creates adverse condition for the establishment of bryoflora on ground, rock and even on other plants. However, at higher elevation (Subtropical band) there were no landslides and the soil type was loamy sandy. This part of the study area was found with high bryophyte diversity. The reason of high bryophyte diversity may be due to above mentioned features of the study area.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- Altogether, 39 species of bryophytes were recorded from the present study. Among them the dominancy was shown by mosses (51%) followed by liverworts (41%) and hornworts (8%). The number of species are very low as compared to the previous study in different geographical region with similar elevation bands. Twenty one families were recorded with dominancy of Aytoniaceae (5 species) followed by Fissidentaceae (4 species).

- There were altogether 3 specific habitats recognized, among them majority of bryophytes belonged to terrestrial habitat (56%).

- *Monosolenium tenerum,* one of the rare species of bryophyte was recorded in this study. *Funaria hygrometrica* was found in both tropical and subtropical band.

- *Philonotis thwaitesii* was found only in sub-tropical band which was previously been reported from tropical band of different studies. Similarly, *Eurhynchium praelongum* was only recorded from highest elevation of the study area, which was found absent within the same elevation range of far western Nepal.

- The bryophyte species richness was found significantly increasing with increase of elevation. There was a statistically significant linear inclining relationship between bryophyte species richness and elevation.

- Bryophyte species richness was found significantly decreasing with increase of total bare ground and canopy cover. However, the relationship between species richness and other environmental variables and soil variables was found statistically insignificant. These features suggests that single environmental parameter cannot alone predict the diversity of the species in a given geographical region.

6.2 Recommendations

- There is lack of knowledge about the bryophytes and its significance. So, awareness about the significance of the bryophytes would help to conserve the species as the pioneer plant for succession.
- Further research should be carried out and the researcher should be encouraged to do various kind of research to predict the relationship of bryophytes and various environmental conditions such as micronutrients of soil, disturbance factors, rock age and rock type and various edaphic and geographic factors.
- As the identification is mainly done considering the morphological features which could also results in wrong identification. So, Molecular studies of the taxa under confusion will lead to correct identification of the taxa.

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APPENDICES

Appendix 1 : Climatological statistics of Tansen station, Palpa

Month	Maximun mean temperature	Minimum mean temperature	Mean Precipitation(mm)
January	19.5	6.2	31.9
February	21.8	8.7	43.4
March	26.2	12.2	30.1
April	29.1	15.3	44.2
May	30.1	16.8	121.1
June	30.0	18.7	316.3
July	28.5	19.2	516.8
August	29.2	19.1	360.6
September	28.9	17.8	186.8
October	27.7	14.8	50.7
November	24.1	10.7	0.0
December	20.6	7.2	11.8

Appendix 2: Systematic position of bryophytes collected from Palpa.

Class	Order	Family	Name of species
Marchantiopsida	Marchantiales	Marchantiaceae	*Marchantia emarginata* Ren. Blume and Nees
			Marchantia polymorpha L.
		Aytoniaceae	*Asterella khasyana* (Griff.) Grolle
			Asterella multiflora (Steph.) Pandé*et al.*
			Asterella wallichiana (Lehm. & Lindenb.) Grolle
			Plagiochasma appendiculatum Lehm and Lindenb.
			Reboulia hemisphaerica (L.) Raddi
		Conocephalaceae	*Conocephalum conicum* (L.) Dumort.
		Dumortieraceae	*Dumortiera hirsuta* (Sw.) Nees
		Monosoleniaceae	*Monosolenium tenerum* Griff.
Jungermaniopsida	Porellales	Lejeuneaceae	*Lejeunea* sp. Lib.
	Jungermanniales	Lophocoleaceae	*Heteroscyphus planus* (Mitt.) Schiffn.
			Heteroscyphus argutus (Reinw., Blume & Nees) Schiffn.
		Jungermanniaceae	*Jungermannia* sp. L.
		Gymnomitriaceae	*Nardia* sp. Gray
		Scapaniaceae	*Scapania* sp. (Dumort.) Dumort.
Polytrichopsida	Polytrichales	Polytrichaceae	*Atrichum undulatum* var. *subserratum* (Harv. & Hook. f.) Paris
			Pogonatum microstomum (R. Br. ex Schwägr.) Brid.
			Pogonatum submacrophyllum Herzog
			Polytrichum commune Hedw.
Bryopsida	Funariales	Funariaceae	*Funaria hygrometrica* Hedw.
	Dicranales	Dicranaceae	*Dicranum setchwanium* Broth.
			Dicranum himalayanum Mitt.
		Fissidentaceae	*Fissidens bryoides* Hedw.
			Fissidens sylvaticus Griff.
			Fissidens taxifolius Hedw.
			Fissidens sp.
		Bruchiaceae	*Trematodon longicollis* Michx.
	Bryales	Bryaceae	*Bryum* sp.
			Bryum caespiticum Hedw.
	Bartramiales	Bartramiaceae	*Philonotis falcata* (Hook.) Mitt.
			Philonotis thwaitesii Mitt.
	Pottiales	Pottiaceae	*Hyophila involuta* (Hook.) A. Jaeger
			Bryoerythrophyllum dentatum (Mitt.) P.C. Chen
	Hypnales	Meteroriaceae	*Meteriopsis reclinata* (Müll. Hal.) M. Fleisch.
		Brachytheciaceae	*Eurhynchium praelongum* (Hedw.) Schimp.
Anthocerotopsida	Anthocerotales	Anthocerotaceae	*Anthoceros punctatus* L.
			Anthoceros sp.
			Folioceros assamicus D.C. Bhardwaj

Appendix 3: List of Bryophytes with their habitat, elevation range of collection and abbreviation

Name of species	Abbreviation	Habitat	Elevation
Astrella khasyana	Astr khas	Lithophytes +Terrestrial	1235m-1586m
Astrella multiflora	Astr mult	Lithophytes+Terrestrial	575m-900m
Astrella wallichiana	Astr wall	Terrestrial	286m-1260m
Coenocephalum conicum	Coen coni	Terrestrial	572m-1586m
Dumortiera hirsuta	Dumo hirs	Terrestrial	273m-1580m
Marchantia emarginata	Marc emar	Lithophytes + Terrestrial	300m-900m
Marchantia polymorpha	Marc poly	Terrestrial	600m
Monosolenium tenerum	Mono tene	Lithophytes + Terrestrial	325m-600m
Plagiochasma appendiculata	Plag appe	Lithophytes+Terrestrial	300m-900m
Reboulia hemisphaerica	Rebo hemi	Lithophytes + Terrestrial	600m-1500m
Heteroscyphus planus	Hete plan	Terrestrial	600m-1500m
Heteroscyphus argutus	Hete argu	Terrestrial	900m
Jungermannia sp.	Jung sp	Terrestrial	600m-1500m
Lejeunea sp.	Leje sp	Epiphytes	900m,1500m
Nardia sp.	Nard sp	Terrestrial	1200m,1500m
Scapania sp.	Scap sp	Lithophytes	300m-1500m
Anthoceros punctatus	Anth punc	Terrestrial	900m,1500m
Anthoceros sp.	Anth sp	Terrestrial	1500m
Folioceros assamicus	Foli assa	Terrestrial	600m,1500m
Atrichum undulatum var. *subserratum*	Atri un su	Terrestrial	1200m-1500m
Pogonatum microstomum	Pogo micr	Lithophytes+Terrestrial	900m-1500m
Pogonatum submacrophyllum	Pogo subm	Lithophytes+Terrestrial	900m,1500m
Polytrichum commune	Poly comm	Lithophytes	300m,900m
Funaria hydrometrica	Funa hydr	Lithophytes+Terrestrial	300m-1500m
Dicranum setchwanium	Dicr setc	Terrestrial	600m-1200m
Dicranum himalayanum	Dicr hima	Terrestrial	1586m
Fissiden bryoides	Fiss bryo	Terrestrial	600m-900m

Fissiden sylvaticus	Fiss sylv	Terrestrial	300m-900m
Fissidens taxifolius	Fiss taxi	Terrestrial	300m-900m
Fissidens sp.	Fiss sp	Terrestrial	1200m
Trematodon longicollis	Trem long	Lithophytes+Terrestrial	300m-900m
Bryum sp.	Bryu spp	Terrestrial	1200m-1500m
Bryum caespiticum	Bryu caes	Terrestrial	1200-1500m
Philonotis falcata	Phil falc	Lithophytes+Terrestrial	600m-1500m
Philonotis thwaitesii	Phil thwa	Lithophytes+Terrestrial	1470m-1586m
Hyophila involuta	Hyop invo	Terrestrial	635m-1140m
Bryoerythrophyllum dentatum	Bryo dent	Terrestrial	300m-1500m
Meteriopsis reclinata	Mete recl	Epiphytes	1480m-1586m
Eurhynchium praelongum	Eurh prae	Epiphytes	1480m-1586m

Appendix 4: Floristic composition of collected bryophytes

	Class	Order	Family	Genus	Species
Liverworts	2	3	10	12	16
Hornworts	1	1	1	2	3
Mosses	2	6	10	13	20
Total	5	10	21	27	39

Appendix 5: Raw Data of soil analysis

Ele.	C %	Status	N%	Status	P(KG/ha)	Status	K (KG/ha)	Status	Soil texture
300	0.69	L	0.06	L	9	VL	250	M	
300	1.35	L	0.12	M	14	L	365	H	
300	1.3	L	0.11	M	20	L	139	M	
300	0.87	L	0.07	L	11	L	216	M	
300	1.89	M	0.16	M	14	L	122	M	Clayey loam
600	1.87	M	0.16	M	8	VL	216	M	
600	2.03	M	0.17	M	8	VL	185	M	Clayey loam
600	2.11	M	0.18	M	11	L	211	M	
600	1.42	L	0.12	M	17	L	211	M	
600	1.18	L	0.1	M	16	L	223	M	
900	1.75	M	0.15	M	6	VL	336	H	
900	2.9	M	0.25	H	15	L	298	H	
900	1.95	M	0.17	M	7	VL	139	M	
900	2.14	M	0.18	M	8	VL	130	M	Loam
900	1.44	L	0.12	M	8	VL	161	M	
1200	1.89	M	0.16	M	55	H	115	M	Loam
1200	1.42	L	0.12	M	67	H	209	M	
1200	1.74	M	0.15	M	67	H	142	M	
1200	1.68	M	0.14	M	69	H	146	M	
1200	1.35	L	0.12	M	43	M	146	M	
1500	0.27	L	0.02	VL	11	L	146	M	Loamy Sand
1500	0.33	L	0.03	VL	7	VL	170	M	
1500	0.9	L	0.08	L	7	VL	151	M	
1500	0.41	L	0.04	VL	6	VL	170	M	
1500	0.27	L	0.02	VL	6	VL	146	M	

Ele.: Elevation; C: Carbon; N: Nitrogen; P: Phosphorous; K: Potassium

Appendix 6: Anova table of CCA

	F	Pr(>F)
Elevation	1.46	0.074
Other plant	1.1	0.325
Rock cover	1.0	0.515
Bare ground	1.29	0.146
Bryophyte cover	1.062	0.357
Canopy cover	0.91	0.578
Herb	1.1	0.280
Carbon	0.95	0.509
Nitrogen	0.94	0.529
Phosphorous	1.55	0.047 *
Potassium	1.19	0.218

Appendix 7: Data of soil analysis**.**

Ele. (m)	**C%**	**N%**	**P(kg/ha)**	**K (Kg/ha)**	**Texture**
300	0.69-1.89	0.06-0.16	9-20	122-365	Clayey loam
600	1.18-2.11	0.1-0.18	8-17	185-223	Clayey loam
900	1.44-2.9	0.12-0.25	6-15	130-336	Loam
1200	1.35-1.89	0.12-0.16	43-69	115-209	Loam
1500	0.27-0.9	0.02-0.08	6-11	146-170	Loamy sand

Ele.: Elevation; C: Carbon; N: Nitrogen; P: Phosphorous; K: Potassium

Appendix 8: Correlation between environmental variables and species richness

Pearson's correlation coefficient matrix												
	Ele.	OP	RC	BG	BC	sppn	canopy	herb	C	N	P	K
Ele		0.08	0.09	0.00	0.85	0.00	0.00	0.35	0.08	0.08	0.24	0.05
OP	0.36		0.00	0.00	0.82	0.10	0.22	0.25	0.95	0.93	0.92	0.31
R C	-0.34	-0.54		0.00	0.33	0.18	0.15	0.10	0.66	0.61	0.27	0.32
BG	-0.65	-0.62	0.67		0.12	0.00	0.02	0.91	0.76	0.75	0.20	0.07
BC	-0.04	0.05	-0.20	-0.32		0.50	0.50	0.79	0.29	0.28	0.91	0.89
sppn	0.79	0.34	-0.28	-0.60	0.14		0.00	0.88	0.45	0.43	0.87	0.26
canopy	-0.61	-0.25	0.30	0.47	-0.14	-0.90		0.33	0.41	0.38	0.81	0.12
herb	-0.20	0.24	-0.34	0.02	0.06	0.03	-0.20		0.93	0.94	0.05	0.81
C	-0.36	0.01	-0.09	0.06	0.22	-0.16	0.17	-0.02		0.00	0.33	0.47
N	-0.35	0.02	-0.11	0.07	0.22	-0.16	0.18	-0.01	1.00		0.34	0.43
P	0.24	0.02	-0.23	-0.27	0.02	0.04	-0.05	-0.40	0.20	0.20		0.24
K	-0.40	-0.21	0.21	0.36	-0.03	-0.23	0.32	-0.05	0.15	0.17	-0.24	

Elevation: Ele.; Other plants: OP; Rock Cover: RC; Bareground: BG; Bryophyte cover: BC; Bryophytes species richess :sppn.; Carbon: C; Nitrogen: N;Phosphorus: P; Potassium: K.

PHOTOPLATES

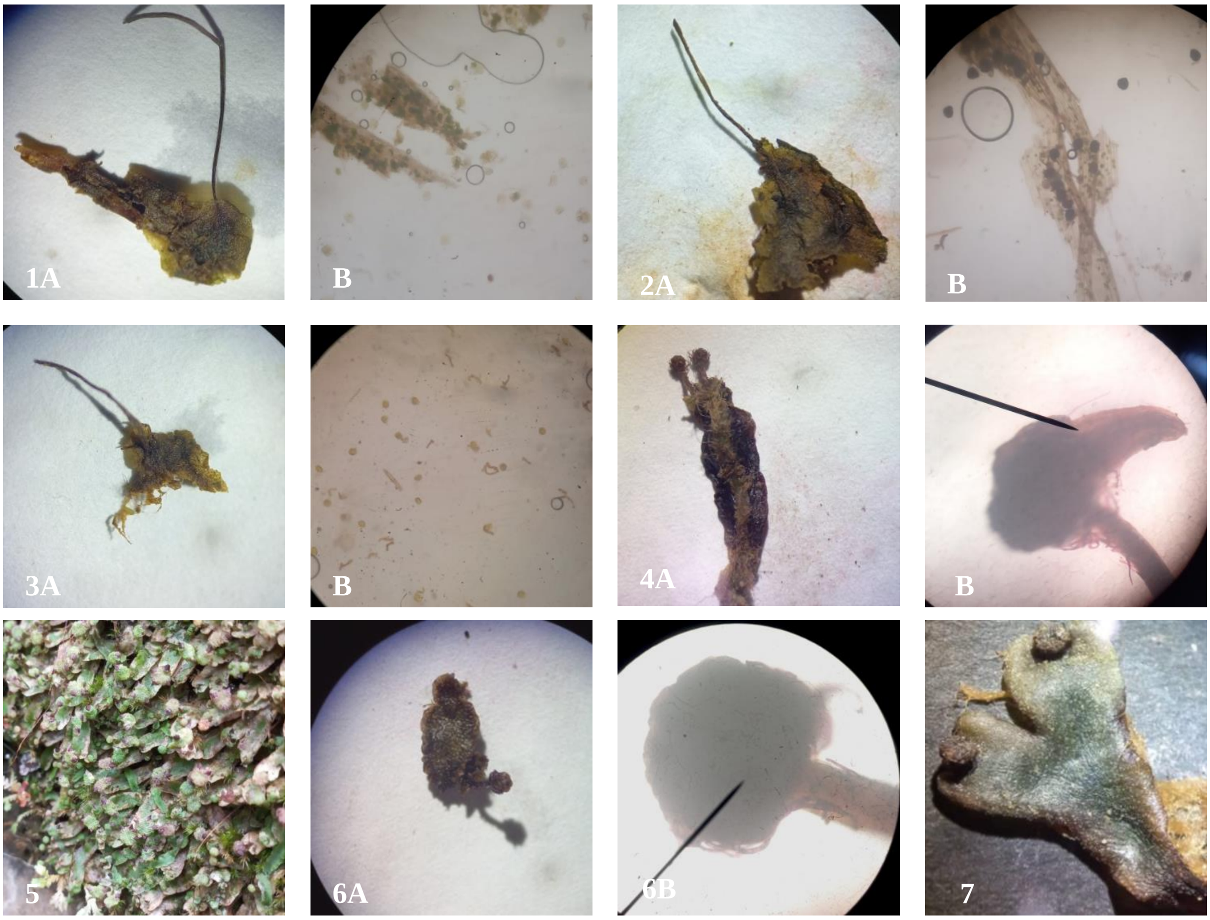

Plate 1: 1A. *Anthoceros punctatus* , **B.** spores ; **2A**. *Anthoceros sp.* , **B.** spores ; **3A.** *Folioceros assamicus*, **B.** spores ; **4A.** *Astrella khasyana* , **B.** sporophyte ; **5:** *Astrella multiflora* habitat; **6A.** *Astrella wallichiana*, **6B.** sporophyte ; **7.** *Conocephalum conicum*

Plate 2: 1. *Dumortiera hirsuta;* **2.** *Marchantia polymorpha;* **3.** *Marchantia emarginata* habitat*;* **4A.** *Monosolenium tenerum* habitat, **4B.** T.S. of thallus; **5.** *Plagiochasma appendiculata* habitat*;* **6.** *Reboulia hemisphaerica* habitat**; 7.** *Heteroscyphus argutus*; **8.** *Heteroscyphus planus*; **9.** *Jungermannia* sp.; **10.** *Lejeunea* sp.**; 11**. *Nardia* sp.

Plate 3: 1. *Scapania;* **2A.** *Atrichium undulatum* var. *subserratum* sporophyte, **2B.** leaf ; **3A.** *Bryoerythrophyllum dentatum*, **3B.** sporophyte ; **4A.** *Bryum caespiticum*, **4B.** sporophyte ; **5.** *Bryum* sp.; **6.** *Dicranum himalayanum***;** **7A.** *Dicranum setchwanium* gametophyte, **7B.** sporophyte; **8.** *Eurhynchium praelongum* habitat

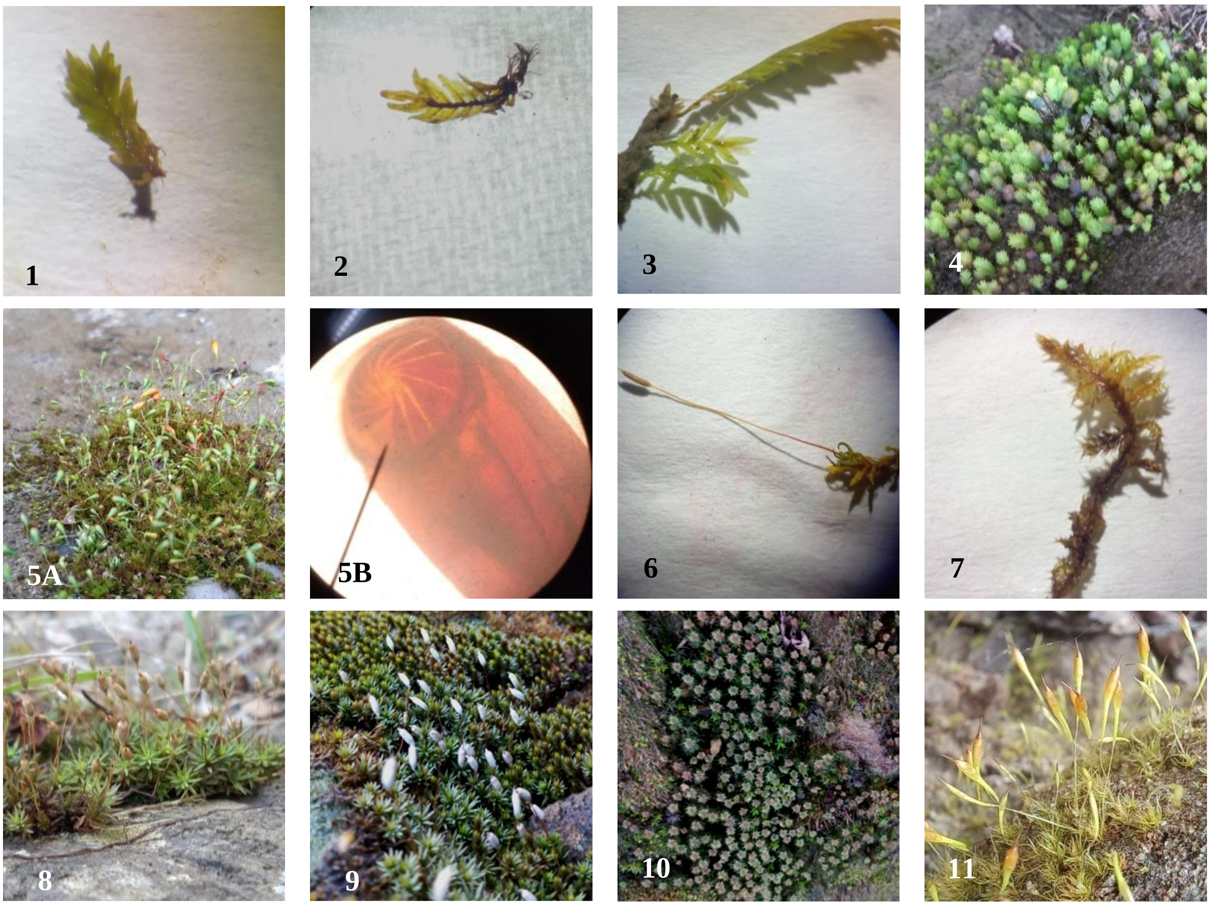

Plate 4: 1. *Fissidens bryoides;* **2.** *Fissidens* sp.; **3.** *Fissidens sylvaticus;* **4.** *Fissidens taxifolius* habitat ; **5A.** *Funaria hygrometrica* habitat; **5B.** peristome; **6.** *Hyophila involuta;* **7.** *Meteriopsis reclinata;* **8.** *Pogonatum microstomum* habitat*;* **9.** *Pogonatum submacrophyllum* habitat; **10.** *Polytrichum commune* habitat; **11.** *Trematodon longicollis* habitat.