Distribution Modelling of Traded Species of *Swertia* L. and Population Ecology of *S. multicaulis* in Nepal

A Dissertation Submitted for Partial Fulfillment of the Requirements for the

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NEPAL

RECOMMENDATION

This is to certify that M.Sc. Dissertation work entitled **"Distribution Modelling of Traded Species of *Swertia* L. and Population Ecology of *S. multicaulis* in Nepal"** has been carried out by Mr. Ashish Dhami under my supervision. This work has been accomplished on the basis of candidates' original research work. This work has not been submitted from any other academic degree. I recommend this dissertation work to be accepted as a partial fulfillment of Master's Degree in Botany at Institute of Science and Technology, Tribhuvan University.

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DECLARATION

The dissertation entitled **“Distribution Modelling of Traded Species of *Swertia* L. and Population Ecology of *S. multicaulis* in Nepal”** is submitted to the Central Department of Botany, Institute of Science and Technology (IOST), Tribhuvan University, Nepal for the Master’s Degree in Botany. The research work was carried out under the guidance and supervision of Prof. Dr. Suresh Kumar Ghimire, CDB, TU.

The entire research work has not been submitted for any other academic degree.

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LETTER OF APPROVAL

The M.Sc. dissertation entitled **“Distribution Modelling of Traded Species of *Swertia* L. and Population Ecology of *S. multicaulis* in Nepal”** submitted by **Mr. Ashish Dhami** has been accepted as a partial fulfillment of the requirements for Master’s Degree in Botany (Plant Systematics and Biodiversity Conservation Unit).

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Ashish Dhami
16th March, 2023

ABBERVIATIONS AND ACRONYMS

°C	: Degree Celsius
Anno. Check. Fl. Pl. Nep. -	: Annotated Checklist of Flowering Plants of Nepal
APG	: Angiosperm Phylogeny Group
asl-	: Above the sea level
AUC	: Area Under the Curve
BM	: British Museum
Bull. Br. Mus. (Nat. Hist.)	: Bulletin of British Museum (Natural History)
C	: Central
ca.	: Circa (Approximate)
CA	: Conservation Area
CDB	: Central Department of Botany
CHELSA	: Climatologies at high resolution for the earth's land surface areas
E	: Eastern
e.g.	: *exempli gratia* or ‘for example’
ed.	: Edition
Enum. Fl. Pl. Nep.	: Enumeration of the flowering Plants of Nepal
et al.	: *et alia* or ‘and others’
Figure	: Figure
Fl.	: Flowering
Fl. Bhutan	: Flora of Bhutan
Fl. Br. Ind.	: Flora of British India
Fl. China	: Flora of China
Fl. Him. Pra.	: Flowers of Himachal Pradesh
Fl. Himalaya	: Flowers of Himalaya
Fl. Kath. Valley	: Flora of Kathmandu Valley
FL. Langtang	: Flora of Langtang
FL. Mustang	: Flora of Mustang
Fr.	: Fruiting

i.e.	: *id est* or ‘that is’
IPCC	: Intergovernmental Panel on Climate Change
KATH	: National Herbarium and Plant Laboratories, Godavari
Kew Bull.	: Kew Bulletin
m.	: meter
mm.	: millimeter
NP	: National Park
No.	: Number
p.	: Page
PAs	: Protected Areas
Pl. Nep.	: Plants of Nepal
Prodr. Fl. Nepal	: Prodromous Florae Nepalensis
RCP	: Representative Concentration Pathways
S	: Southern
S.N.	: Serial Number
Sp.	: Species
TI	: University Museum, University of Tokyo, Japan
TU	: Tribhuvan University
TUCH	: Tribhuvan University Central Herbarium
Vol.	: Volume
W	: Western
WC	: World Clim

ABSTRACT

The genus *Swertia* has a long history of usage in Indian, Tibetan, and Nepalese traditional medicine. The species of the genus have been widely used as a natural remedy for a variety of ailments. Because of high ethnomedicinal and pharmacological values, *Swertia* has become a major export of medicinal plants from Nepal and ranks as the second most traded genus in the country. The growing demand for medicinal plants has led to unsustainable harvesting, making conservation efforts necessary. Additionally, climate change has also affected the accessibility and productivity of medicinal plants. To address this, firstly, distribution models of traded species of *Swertia* were developed based on maximum entropy and secondly, an ecological study of less studied *S. multicaulis* was conducted. The study identifies the potentially suitable areas of seven commercially traded species of *Swertia* under the current climate conditions and predicts a significant decrease in suitable areas for all of the species by 2050 and 2070 AD in both representative concentration pathways (RCP 6 and RCP 8.5), with the exception of *S. racemosa*.

The ecological study was conducted at four different sites around the Gosainkunda area in Lamtang National Park. The study involved a total of 40 plots of 3m^2 and 200 sub-plots, each measuring 1m^2, that recorded the presence of *S. multicaulis* in open alpine meadows on north-east facing slopes at different elevations. The overall density was found to be 11.33 plants/m^2. The densities of young and adult reproductive plants decreased significantly with increasing elevation. In the lower elevation sites, the proportion of young plants was higher, indicating better regeneration there. Despite the similar vegetative and reproductive traits among all populations studied, the higher elevation population near Suryakunda, which featured rocky terrain, had a higher below-ground biomass allocation. The study also revealed the negative effect of litter cover on the total plant density of *S. multicaulis*. But the density positively correlated with greater distance from the nearest trail. The findings of the ecological study of *S. multicaulis* as well as the habitat suitability map for seven traded species of *Swertia* created by the distribution models can be utilized as a reference for developing conservation policies for such species and also prioritizing those areas as potential areas for cultivation or harvesting purposes. For species like *S. multicaulis*, with very limited climatic suitability in a specific region, our study recommends facilitated assisted migration to predicted suitable areas as the optimal solution to ensure their future.

Key Words: medicinal plants, climate change, distribution models, conservation

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CHAPTER I: INTRODUCTION

1.1 Background

The utilization of medicinal plants in healthcare has been practiced since the earliest civilizations of humanity (Ghimire, 2008). Medicinal plants have long been used to treat and alleviate various disease symptoms in many developing countries and is still a major source of medication for a wide range of ailments (Applequist *et al.*, 2020). Various traditional healing systems, including Ayurveda, Unani, Chinese, and Tibetan, have long recognized the value of plants in medicine. Additionally, medicinal plants and their derivatives are commonly used in other traditional medical systems such as Siddha and homeopathy, as well as modern allopathic medicine (Ghimire *et al.*, 2008). Such plants have been recognized as valuable commodity in Nepal with a great potential for economic development due to their high social, cultural, and economic value (Ghimire *et al.*, 2016). Trade of such medicinal plant has become major income generating activities in the high mountains of Nepal (Ghimire *et al.*, 2016; Cunningham *et al.*, 2018; Poudeyal *et al.*, 2019).

Swertia has been used in Indian, Tibetan, and Nepalese traditional medicine systems for centuries. It has been widely used as a natural remedy for a variety of ailments, including cough and cold, headache, and fever (Joshi, 2008; Uprety *et al.*, 2010; Acharya & Kaphle, 2015; Uprety *et al.*, 2016). The entire plant or parts of it, such as the leaves, stems, and roots, are utilized for medicinal purposes. The therapeutic effects of *Swertia* are primarily associated with high concentration of xanthones along with other secondary metabolites; flavonoids, triterpenoids and iridoid glycosides which are effective against a wide range of diseases (Negi *et al.* 2011; Timsina *et al.*, 2018; Kshirsagar *et al.*, 2019). The high ethnomedicinal use value has made *Swertia* one of the largest export commodities under medicinal plant sector from Nepal (Joshi, 2008; Phoboo *et al.*, 2010; Barakoti *et al.*, 2012; Shrestha *et al.*, 2016, Cunnigham *et al.*, 2018). This has led *Swertia* to become the second most traded genus in Nepal with nine traded species; *Swertia chirayita, S. angustifolia, S. tetragona, S. racemosa, S. ciliata, S. dilatata, S. multicaulis, S. alata, and S. nervosa* (Shrestha *et al.*, 2010; Pyakurel *et al.*, 2019).

Trade of medicinal plants has grown quickly over years as a result of rising global demand for natural products, particularly from the Indian and Chinese pharmaceutical and the other aromatic sectors (Vasisht *et al.*, 2016). Nepal has been traditionally exporting medicinal plants for at least a thousand years, primarily to China and India (Hamilton, 1819, as cited in Pyakurel *et al.*, 2019). According to data from the United Nations International Trade Statistics Database, Nepal exported over 10,000 tons of medicinal plants valued at approximately $60 million in 2014, to over 50 countries (Ghimire *et al.*, 2016). Such largescale trade of MPs indicates increasing demand in the global scale (Pyakurel *et al.*, 2017 & 2018). This increasing demand may lead to intense premature or over-harvesting (Ghimire *et al.*, 2008) and may push many MPs population to extinction making conservation and management a key issue (Ghimire *et al.*, 2005; Bhattarai & Ghimire, 2006, Joshi & Joshi, 2008, Uprety *et al.*, 2016, Pyakurel *et al.*, 2019, Applequist *et al.*, 2020).

The Earth's systems are rapidly undergoing changes of enormous magnitude due to anthropogenic pressures on biodiversity (Araujo *et al.*, 2019). The temperature in the Himalayas has increased by 1.5 ºC (0.06 ºC per year) and the mean annual rainfall has increased by 163 mm or 6.52 mm per year which is considerably higher than the global average causing significant change in vegetation phenology across the Himalayas (Shrestha & Bawa, 2012). The average start of the growing season also has advanced by 4.7 days or 0.19 days per year. The impact of climate change on medicinal plants could potentially influence both the accessibility and productivity of these plants, as well as alter the phytochemical content of surviving populations, which in turn may have an impact on their pharmaceutical properties (Applequist *et al.*, 2020).

Species distribution models (SDMs) have become a useful tool in conservation biology, ecology, and biogeography. It creates a correlative model of the environmental conditions which meet a species' ecological needs and predict the relative suitability of habitat under which a species can persist (Phillips *et al.*, 2006; Elith *et al.*, 2011; Warren & Seifert, 2011; Peterson & Soberón, 2012). They have been used to map species distributions and make predictions about the occurrence or abundance of a species in unsampled locations (Qiao *et al.*, 2015). Moreover, distribution models built on present day environmental data can also be used to predict potential suitability in the future time periods based on projections of future climates using global circulation models (Guillera-Arroita *et al.,* 2015; Guisan *et al.*, 2017). Understanding the environmental requirements of species and mapping their distributions over space and time has become an important aspect of many biological analyses, especially in field of conservation and management (Zurell *et al.*, 2020) and is considered a significant research tool (Guisan & Thuiller, 2005).

Additionally, understanding plant population density, structure and plant functional traits is important for ensuring the long-term persistence of plant populations, as plant species, particularly medicinal plants in alpine areas like *S. multicaulis* (Rijal, 2009), are experiencing excessive population declines due to environmental changes and human influence (Ghimire *et al.*, 2004; Poudeyal *et al.*, 2019). The plant functional traits like vegetative (like leaf size, plant height) or reproductive (like flower or fruit numbers) traits or the resource allocation pattern are considered important fundamental parameters in the plant ecology that reflect the individual adaptation of the species within a specific environmental condition (Körner, 2003; Fan & Yang, 2009). So, understanding the variations in these plant traits is important for conservation planning to secure long-term persistence.

Medicinal plants have a limited habitat range which make them vulnerable to environmental alterations, habitat degradation, and destructive harvesting (Ghimire *et al.*, 2008). Climate change along with unsustainable harvesting pose significant challenges to their conservation. Despite these challenges, there is still a lack of sufficient information on the distribution, their population status and the environmental conditions necessary for the survival of these species. For this, it is important to have an understanding of the ecological niches, population status, spatial distributions of the species, and prioritizing conservation of their habitat to prepare for and address climate change impacts.

1.2 Objective

The general objective of the study is to estimate the potential distribution of traded species of *Swertia* and assess the population status of *S. multicaulis.* The other specific objectives are:

1. To identify the main ecological determinants of the species within its entire range in Nepal.
2. To identify potential areas of suitable and unsuitable habitats for traded species of *Swertia* in Nepal.
3. To forecast the potential distribution of traded species of *Swertia* in 2050 and 2070.
4. To study the variation in growth strategies and plant performance of *Swertia multicaulis* in relation with different environmental factors.

1.3 Limitations

Spatial distribution models perform better with a larger number of occurrence points, resulting in a more accurate prediction. With decreasing sample size, model accuracy also decreases. Another issue is the uncertainty in the location recorded for the species in various herbaria or online databases. The collection of many presence records of a species from a specific area only also creates spatial autocorrelation. If not addressed, this issue can significantly raise the uncertainty in the model's ability to make accurate predictions. In addition to that, SDMs do not consider factors such as biotic interactions, geographic barriers, dispersal limitations. It also does not consider extreme events like flood, landslide causing loss of suitability. SDMs can only predict what areas have suitable climate for the species to be there in current or future climate. This does not mean that the species are actually present there. So, in reality species may not occupy all areas which are predicted as suitable. Besides that, corona pandemic, limited resource and time were also the limiting factor for this work. In case of the population ecology of *S. multicaulis*, long-term studies would have explained more accurately the growth strategies and plant performance.

CHAPTER II: LITERATURE REVIEW

2.1 Genus *Swertia* L.

The genus *Swertia* is diverse and distributed in the mountainous regions of tropical Asia, Europe, America and Africa (Brahmachari *et al.*, 2004). The genus is principally Asiatic with its highest distribution in the Sino-Himalayan region (Negi *et al.*, 2011). The species of the genus *Swertia* are annual or perennial herbs with tetramerous or pentamerous flowers. Rotate corolla and presence of corolline nectariferous glands are considered as distinguishing feature that separates *Swertia* from related genera (Nampy *et al.*, 2015). Furthermore, color of petals, the number and shape of these glands have also been used as diagnostic characters for delimiting the different species within the genus (Rijal, 2009).

Carolus Linnaeus (1753) was the first person who described species of *Swertia* in his *Species Plantarum.* Similarly, a number of infrageneric classifications were attributed to the genus *Swertia* by Clarke (1883) who divided *Swertia* genus into three subgenera: Ophelia, Eu*Swertia* and Poephila. Burkill (1906) discussed the taxonomy of nine species of *Swertia* occurring in India and China and described three new species. In context of Nepal, Smith in 1970 has described three species of *Swertia*: *S. acaulis, S. gracilescens* and *S. stantonii* (Joshi & Joshi, 2008). 'An Enumeration of Flowering Plants' of Nepal has described 27 species and five varieties of *Swertia* (Hara, *et al.*, 1982). 'Flora of Kathmandu Valley' has described four species of *Swertia* (Malla, *et al.*, 1986) found around the Kathmandu Valley. Three species of *Swertia* have also been listed in the 'Vegetation and Flora of South-West Kathmandu Valley' (Bania & Shakya, 1999). Similarly, Press *et al.* (2000) have listed 28 species and five varieties of *Swertia* from Nepal. Chassot (2003) described *S. barunensis* as a new *Swertia* species from east Nepal. Rijal and Joshi (2007), have studied the morphological variation among 11 *Swertia* species. Joshi and Joshi (2008) have prepared a checklist of 31 species of *Swertia* from Nepal based on their morphological characteristics. Similarly, taxonomic study of seven species of *Swertia* has been done by Rijal (2009). In recent checklist, Rajbhandari *et al.* (2015 & 2017) listed only 26 species with 3 varieties of *Swertia*. They have treated *S. teres* and *S. racemosa* as the same and included *S. gracilescens* which was treated as a synonym of *S. paniculata* in Press *et al.* (2000). Tiwari *et al.* (2019) reviewed the endemic plants of Nepal and found 3 *Swertia* species (*S. acaulis*, *S. barunensis* and *S. nepalensis*) to be endemic of which *S. barunensis* and *S. nepalensis* were not listed in Rajbhandari *et al.* (2015 & 2017). In the more recent publication by Shrestha *et al.* (2022), 29 species of *Swertia* including 3 species endemic to Nepal has been listed. Additionally, *S. paniculata* var. *gracilescens* and *S. dilatata* var. *pilosa* have been listed as endemic to Nepal. *S. barunensis*, *S. wardii* and *S. virescens* were three species which were not listed in Press *et al.* (2000) or Rajbhandari *et al.* (2015 & 2017).

2.2 Plant Population Structure and Functional Traits

Plant population ecology is the study of populations of a particular species of plants within a specific area. It encompasses the examination of factors such as population size, distribution, growth, and demographic structure, as well as the interactions between these populations and their environment. The basic characteristic of a population is its size or density. Population density, along with individual-level traits, like vegetative growth, reproductive vigor or the resource allocation patterns (Fan & Yang, 2009) are considered important parameters in plant ecology which reflect the adaptability of a species in a specific environmental condition. Many studies exist in the field of plant population ecology of Nepalese flowering plants (Ghimire *et al.*, 1999; Madhav *et al.*, 2010; Bhattarai *et al.*, 2014; Dhamala *et al.*, 2020); however, very few are focused on analyzing density-based population structure (Ghimire *et al.*, 2005; Ghimire *et al.*, 2008; Chapagain *et al.*, 2019; Poudeyal *et al.*, 2019). These studies typically have examined the effects of disturbances in different habitat types. Population structure analysis have also been used to predict the regeneration status based on the relative proportions of the young, juvenile and adult plants (Ghimire *et al.*, 2005). So, understanding the plant population dynamics and the variation in their functional traits is essential in conservation planning to ensure the long-term persistence of populations since plant species are experiencing excessive decline of the original population, especially in the case of medicinal plants in the alpine regions (Ghimire *et al.*, 2004; Poudeyal *et al.*, 2019).

2.3 Species Distribution Models

Species distribution models (SDMs) also known as “ecological niche models” (Peterson *et al.*, 1999), or “bioclimatic envelope models” (Araujo & Peterson, 2012) use the locations of collection records to map the distributions of species, making them a powerful tool in conservation biology, ecology and biogeography (Feeley & Silman, 2011). The earliest found examples of modelling strategies using correlations between distributions of species and climate seem to be those of Johnston (Guisan & Thuiller, 2005), predicting the invasive spread of a cactus species in Australia. The origins of computer-based predictive modeling of species distribution can be traced back to the mid-1970s (Guisan & Thuiller, 2005). Consequently, there has been a substantial increase in the number of publications related to this field. Species distribution modelling has emerged as a crucial technique in addressing a wide range of ecological, biogeographical, and evolutionary issues and more recently in conservation biology and climate change research.

There have been various studies and research conducted in Nepal related to species distribution modeling. Gajurel *et al.* (2014) predicted suitable area for *Taxus wallichiana* in Far-Western Nepal which had not been previously reported from that area despite of intensive studies. They found temperature playing key role as a bioclimatic variable for species suitability. Ranjitkar *et al.* (2014) used the BiodiversityR (R package) to do ensemble modelling to identify the bioclimatic variables defining the climatic space for Trans-Himalayan Nyctaginaceae species *Boerhavia diffusa* and *Oxybaphus himalaicus*. They concluded that the ideal conditions for *B. diffusa* were situated in the lowlands of Nepal, which are both well-drained and hot, whereas the favorable conditions for *O. himalaicus* were identified in the valleys of the highlands. They also found that bioclimatic variables that surrogates for the arid environment were important delimiting factor of the climate space of the *O. himalaicus*. However, in case of *B. diffusa*, the temperature during the driest quarter, the rainfall in the driest month, and the rainfall during the wettest quarter were important. Shrestha and Bawa (2014) predicted the current distribution and future distributions of *Ophiocordyceps sinensis* in three different time periods (2030, 2050, and 2070). They found about 6.02% (8,989 km^2) area occurring in 26 mountainous districts of Nepal suitable for *O. sinensis*. They showed that predicted suitable habitat of *O. sinensis* would expand by 0.11-4.87% over current suitable habitat in the future using global circulation model, HadGEM2-CC.

Bobrowski and Udo (2017) compared the CHELSA and WORLDCLIM climate dataset to model the potential distribution of *Betula utilis* in the Himalayan region. Based on their findings, the upper subalpine belt in the western and central Himalayan regions was identified as the most suitable area for the studied species, with temperature and precipitation related climatic variables being the primary contributing factors.

Shrestha *et al.* (2018) analyzed the potential impact of climate change on the distribution of six invasive alien plants of Nepal. According to the study, *Parthenium hysterophorus* was found to have the largest climatically suitable area under current climatic conditions, while *Mikania micrantha* had the smallest. The study also predicted that the climatically suitable areas for all six invasive species will increase across Nepal by 2050, under the RCP 4.5 climate change scenario, with further expansion expected by 2070.

Rana *et al.* (2020) conducted ensemble species distribution modeling to define the climatic ranges of six frequently traded medicinal and aromatic plants (MAPs) in the highlands of Nepal. The study found that "Spikenard" (*Nardostachys jatamansi*) had a high suitability under both the current and future climate scenarios, while "Aconite" (*Aconitum spicatum*) had low suitability. The study also indicated decrease in the suitable area for *Valeriana jatamasi* and *Paris polyphylla* in future 2070. In another study, Rana *et al.* (2021) also used ensemble species distribution modelling for phylogeographic analysis to reveal the genetic structure and lineage differentiation of *Incarvillea arguta* in the Himalaya-Hengduan Mountains biodiversity hotspot. The results showed that five temperatures related and four precipitation related bioclimatic variables as important variables.

Poudel *et al.* 2020 used Maxent modeling to predict the distribution of invasive weed, *Ageratina adenophora* in the Chitwan-Annapurna Landscape (CHAL) of Nepal under current condition and three future climate change trajectories based on three representative concentration pathways (RCPs 2.6, 4.5, and 8.5) in two different time periods (2050 and 2070). They found 38% (12,215 km^2) of the total area of CHAL climatically suitable for *A. Adenophora* under current climate which is predicted to increase under RCP 2.6 and RCP 4.5 for both the years 2050 and 2070 but decrease in RCP 8.5. They also suggested, *A. Adenophora* will colonize areas at higher elevations in the future as the upper elevational distribution limit is expected to expand by 31- 48 m in future.

Kunwar *et al.* (2020) conducted distribution modeling for, *Dactylorhiza hatagirea, Paris polyphylla* and combined three species of *Taxus (T. contotra, T. mairei* and *T. wallichiana)*. They found more suitable area for *Taxus* species (41,172 km^2) under current climate. They estimated 25,479 km^2 to be suitable area for *D. hatagirea*. However, Shrestha *et al.* (2021) disputes this estimate for some districts in western Nepal and instead claims that 10,839 km^2 would be a more accurate suitable area. Shrestha *et al.* (2021) identified annual mean temperature, seasonal nature of the precipitation and annual precipitation as the most significant variables affecting the distribution of *D. hatagirea*. They also predicted significant loss of habitat for *D. hatagirea* in Nepal by 2050 and 2070, based on all three different global circulation models and under both the RCP4.5 and RCP8.5 scenarios. They also found that climatically suitable habitat for the species would shift to higher altitude areas.

Poudeyal *et al.* (2021) used MaxEnt modelling to identify areas with optimal habitats for production alternatives of *Neopicrorhiza scrophulariiflora.* They found elevation to be the most influential predictor (51.4% contribution) for the distribution. They predicted the area of suitable habitat in Nepal was 11,617 km^2 with more suitable areas concentrated within a limited elevation range of 4000-4400 m.

Bobrowski *et al.* (2021) applied generalized linear models for comparing and evaluating global climate datasets based on CHELSA and WORLDCLIM climate datasets for the ecological niche of *Betula utilis* in Nepal under current and future climate conditions. They found the performance of the models based on CHELSA to be better than models based on WORLDCLIM. They also predicted an increase in potentially suitable habitat for *B. utilis* under both RCPs 4.5 and 8.5 in both climatic datasets CHELSA and WORLDCLIM.

Shrestha *et al.* (2022) analyzed the potential distribution of twenty-nine species of medicinal and aromatic plants in Nepal under current climate. They also predicted the potential future distribution based on the representative concentration pathway (RCP) 6.0 using an ensemble modeling. They combined 12 global circulation models and used in their ensemble modelling. On average, 5821 km^2 of area was predicted to be climatically suitable for individual species modeled. In the future, the average suitable area would decline by 10.4% on average. More than 50% reduction in suitable areas is predicted for nineteen species in the future but more than 50% increase for six species.

Kunwar *et al.* (2023) analyzed the current and future potential distribution of seven medicinal plants from sub-tropical to alpine, in two different Shared Socioeconomic Pathways (SSP 4.5 and 8.5) scenarios using ensemble species distribution modeling. The study found that elevation, mean diurnal and annual temperature range and precipitation of warmest and coldest quarter contributed in medicinal plant distribution in Nepal. The results showed that by 2050 and 2070 (SSP 4.5), suitable distribution area of three high elevation species (*Aconitum wallichii, Nardostachys jatamansi,* and *Neopicrorhiza scrophulariiflora*) increased in all six provinces except a loss of *A. wallichii* in the Karnali province. But three sub-tropical and temperate species (*Berginia ciliata*, *Paris polyphylla*, and *Valeriana jatamansi*) showed a decrease of suitable area by up to 24%.

CHAPTER III: MATERIALS AND METHODS

3.1 Study Area

The objectives of our current study were twofold: first, to develop a distribution model of traded species of *Swertia*; and second, to conduct a population study of *S. multicaulis*. The SDMs in this study were conducted within the political boundaries of Nepal. The whole work is based on the occurrence records of herbarium vouchers from different herbaria and their databases and field observations within Nepal. For the population study of *S. multicaulis*, Lamtang National Park (LNP) was selected.

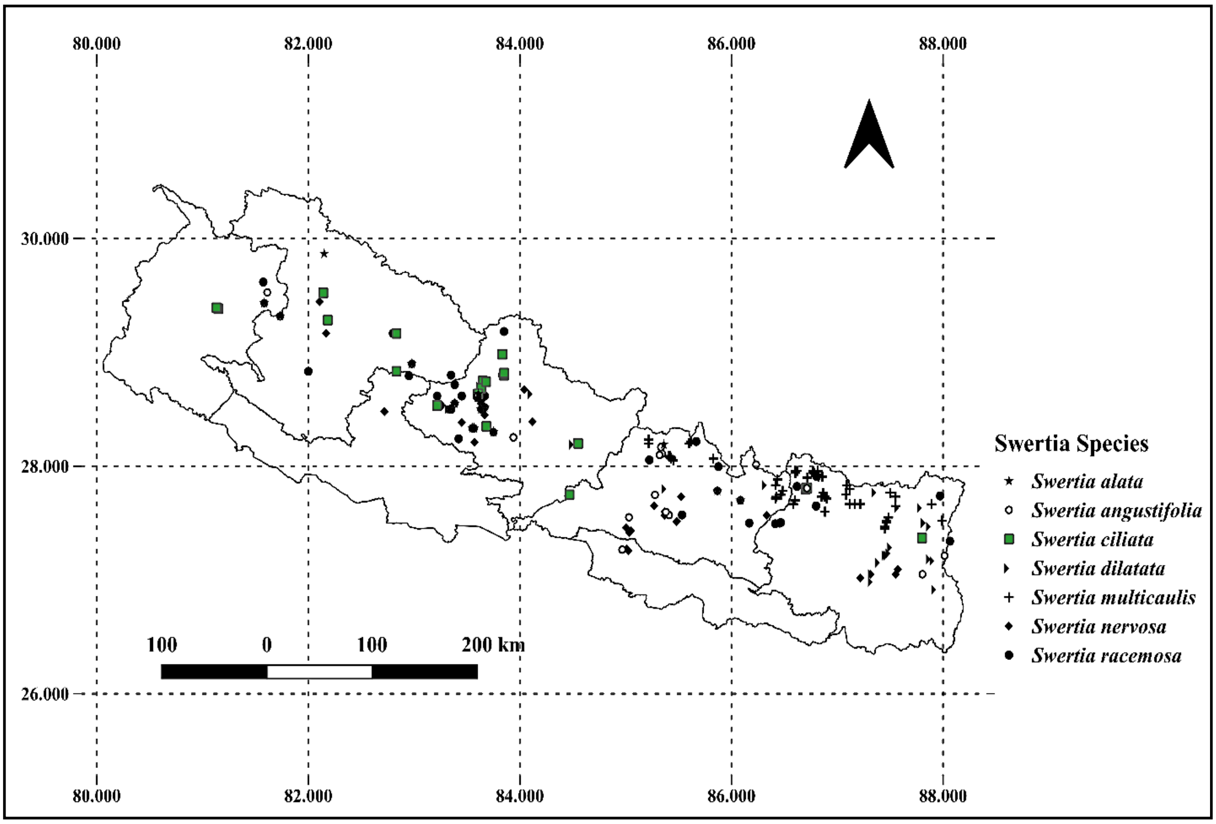

Figure 1: Map of the study area with occurrences of *Swertia* species

3.1.1 Geographic location and physiography

Nepal is located on the southern slope of the central Himalaya which occupies a transitional zone in the central Himalayas, which is a major biodiversity hotspot having floras of the eastern and western Himalaya (Shrestha & Joshi, 1996). The mountain region is divided into three major geographical division i.e., Western Himalayan Section, Central Himalayan Section and Eastern Himalayan Section where the whole Nepal lies in the Central Himalayan Section (Zurick *et al.*, 2005, Tiwari *et al.*, 2019).

Nepal covers an area of 147,516 km^2 (after the release of the new map on 20th May 2020). It has the widest elevation gradient, ranging from 64 masl to the Mount Everest, the highest point in the world at 8,848.86 masl within an aerial distance of about 150 km. This vast altitudinal range results in diverse physiographic, climatic, topographic, and edaphic conditions, leading to a rich biodiversity that ranges from subtropical to alpine conditions (Dhital, 2015). The phyto-geographical provinces are characterized by various vegetation types, including tropical lowland rainforests, temperate oak and coniferous forests in the mid-hills, and dwarf scrubs of rhododendron and alpine meadows in the higher regions (Miehe *et al.*, 2015).

The population ecology of *S. multicaulis* was studied in four different places around Gosainkunda area in LNP (Figure 2). LNP is located between 28.00° to 28.20° N and 85.15° to 86.00° E with unique floral and faunal diversity with rich cultural heritage as well. It has an area of 1710 km^2 which extends over three districts; Rasuwa, Sindhupalchok and Nuwakot. The major portion of LNP is covered by rock and ice (60.73%) and the elevation ranges from 792 masl in the Bhotekoshi river to the peak of Langtang Lirung at 7245 masl (LNP, 2019).

3.1.2 Climate

The climate in Nepal is primarily shaped by three key factors, namely the altitude, monsoons, and westerly disturbances during the winter. It exhibits four distinct seasons, which are pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November), and winter (December-February) (WECS, 2011). Other important climatic factors influencing biodiversity and the distribution of flora and fauna include humidity, temperature, and aspect. The effect of climatic variation is reflected in the habitats, vegetation, and fauna existing in the country.

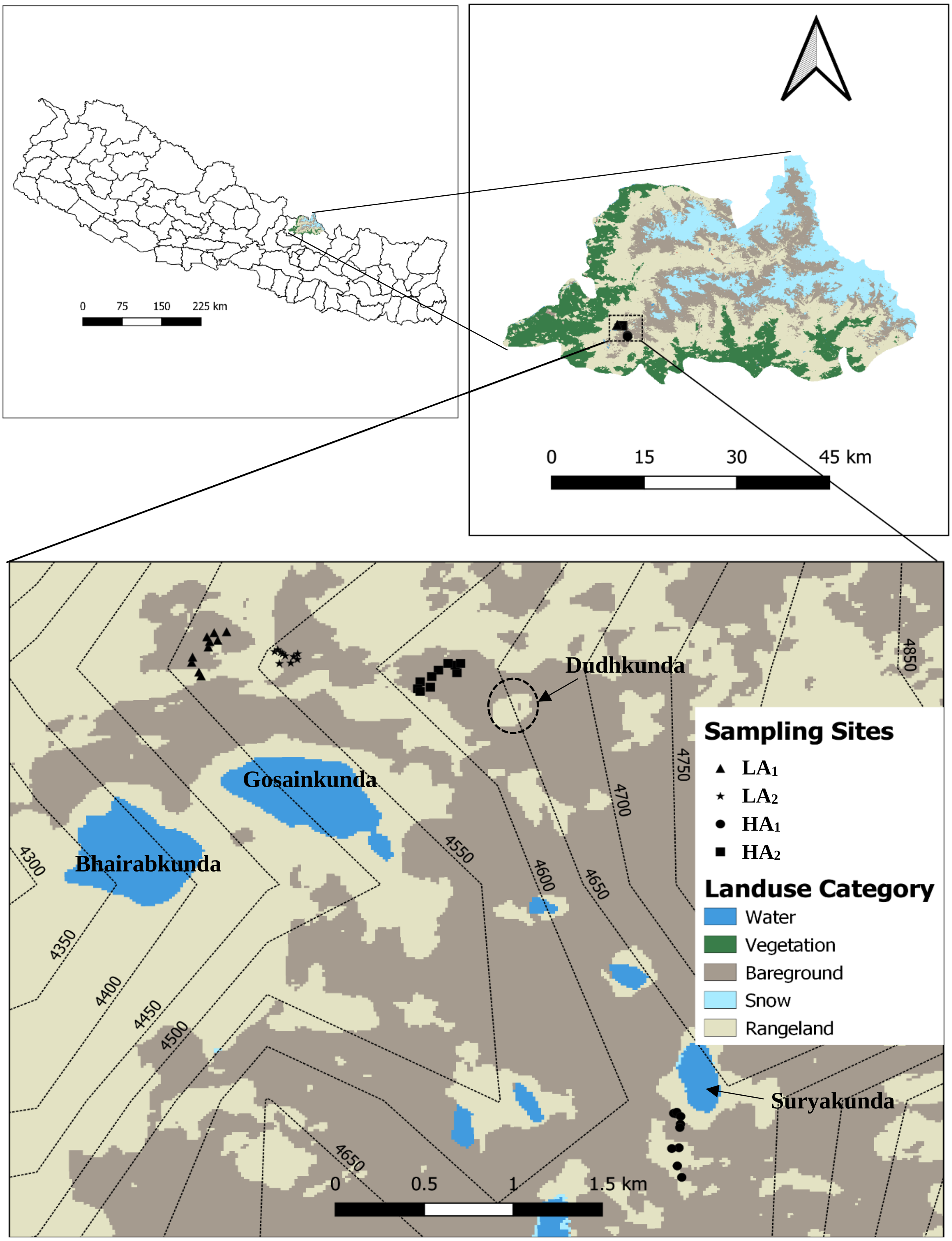

Figure 2: Map of Lamtang National Park with sampling sites for population study of *Swertia multicaulis* (Land use Category is based on Sentinal-2, 10 m resolution GeoTiff file from https://www.arcgis.com/apps/instant/media/index.html?)

3.1.3 Rainfall

Most of the rainfall in Nepal occurs between June and October due to the summer monsoon. The amount and distribution of precipitation varies across the country, with the east receiving the first rain and the west getting it later. About 80% of the annual rainfall comes from the summer monsoon, which delivers less rainfall in the western mountainous area than in the eastern regions (PAN, 2009). However, in winter, precipitation is slightly more than in the eastern and central regions. The High Himalayas receive the lowest amount of rainfall (400-1000 mm), while other regions receive more rainfall (1500-2000 mm) (DHM, 2017). In terms of each district's annual rainfall, Mustang receives the least amount with 257.8 mm, while Kaski receives the highest with 2710.5 mm (DHM, 2017).

In the LNP, the rainfall is mostly dominated by southern monsoon occurring between June to September. In the year 2019, the data from the DHM at Dhunche Weather Station showed the maximum rainfall of 519.2 mm in July and no rainfall in December (Figure 3) with the annual precipitation of 1931.2 mm.

3.1.4 Temperature

Temperature varies with topographic variations. In general, the average temperature drops by 6 ºC for every 1,000 m increase in altitude (Jha, 1992). Latitude also affects the temperature. As latitude increases the intensity of the solar energy that strikes an area decrease. In Nepal, the temperature falls slowly during the monsoon because of heavy clouds and rain and continue to drop as winter starts. The maximum mean temperature can reach on an average 30.3°C in Tarai region to less than 0°C in High Himalaya (DHM, 2017). In the Mid-hills, annual minimum and maximum temperatures are 13.3ºC and 24.6ºC. The temperature gradually decreases with increasing elevation. The both annual minimum and maximum temperature has increased by 0.056°C/year and 0.002°C/year (DHM, 2017) during 1971-2014 and increase is more in higher altitude regions.

In LNP, the average maximum temperature was recorded in the month of June (25.1°C) and the minimum average temperature in December (3°C) at the nearest weather station in Dhunche (Figure 3).

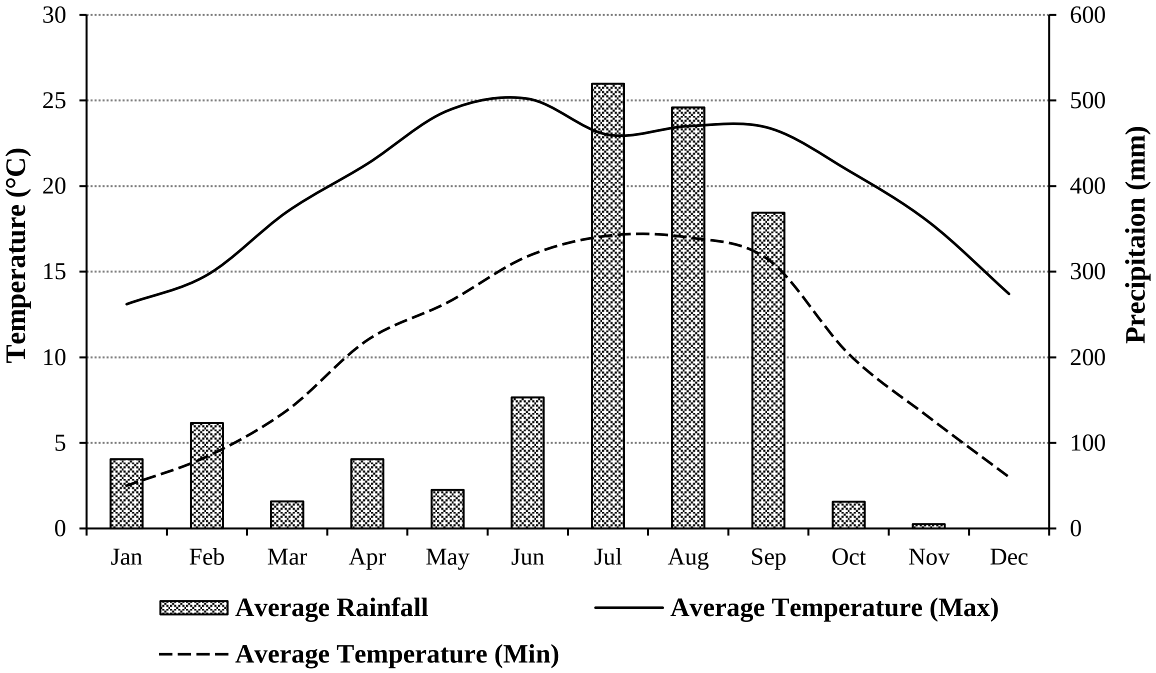

Figure 3: Monthly average precipitation and temperature (minimum and maximum) in 2019 at Dhunche Weather Station, Rasuwa

3.2 Species Selection

A total of nine species of the genus *Swertia* are under commercial trade in Nepal (Shrestha *et al.*, 2010; Pyakurel *et al.*, 2019) and the genus has been ranked in second place in terms of the number of species under trade. Therefore, the study focuses on the distribution modelling of seven species of the genus *Swertia* (*S. alata, S. angustifolia, S. ciliata, S. dilatata, S. multicaulis, S. nervosa* and *S. racemosa*) excluding *S. chirayita* and *S. tetragona. S. chirayita* is distributed in approximately 50 districts of Nepal and extensively cultivated in the eastern Himalayas (Pyakurel & Baniya, 2011; Cunningham *et al.*, 2018; Gaire *et al.*, 2019) and hence was not selected. However, for *S. tetragona*, the presence records available in various herbaria were insufficient, and the habitat locations could not be traced during field visits. *S. multicaulis* was selected for the population study because it is the only *Swertia* species found in the alpine region that is under trade. The detailed morphological and distribution account of the seven species of *Swertia* selected for study is given in Appendix 30.

3.3 Species Distribution Modelling

3.3.1 Occurrence data

A database of the occurrence of all the species was prepared based on herbarium specimens deposited in major herbaria around the world that hosted collections from Nepal. Herbarium specimens preserved at Tribhuvan University Central Herbarium, TU (TUCH) and National Herbarium and Plant Laboratory in Kathmandu (KATH) were primarily examined. Furthermore, various sources were considered to gather data, including online databases such as Tokyo University Herbarium (TI; http://umdb.um.u-tokyo. ac.jp/DShokubu/nepal/Seedplants) and Royal Botanical Garden Edinburgh Herbarium (E; http://data.rbge.org.uk/search/herbarium/), as well as the Flora of Nepal (httpp://www.floraofnepal.org/data) and the Global Biodiversity Information Facility (GBIF; https://www.gbif.org/). The relevant information was also collected from various literatures. In addition, some observations form online data platform like iNaturalist worldwide (https://www.inaturalist.org/) have been incorporated in the model building. And the remaining occurrence points were collected during field visits to various locations.

The information from the herbarium specimen or from opportunistically collected data by volunteer observers can make a valuable contribution to the purpose of our study. However, such data has a high risk of bias and errors and should be processed correctly (Ranjitkar *et al.*, 2014; van Eupen *et al.*, 2021). Additionally, certain areas may have been sampled more extensively than others, or the geographic location of species occurrences may have been inaccurately recorded, which can introduce sampling bias. Such geographic bias in sampling can, in turn, lead to environmental bias in the sampled data. So, data must be used with caution to prevent geocoding errors or confused taxonomic status. As it is a standard practice to remove all but one record per cell to reduce the effects of sampling bias on models, all the duplicates within the single cell were removed leaving only one record using the function elimCellDups() of the R package enmSdm (Smith, 2022). Then the presence records were used for further bias correction and ultimately in the variable selection and species distribution modelling.

3.3.2 Predictor variables

3.3.2.1 Bioclimatic variables

Environmental predictors reflect the species' physiological needs. There are many sources of climate data that are available. The most commonly used in niche/distribution modeling and freely available is the WORLDCLIM climate dataset (Bobrowski *et al.* 2021). As potential climatic predictors, a total of nineteen bioclimatic variables were obtained from a WORLDCLIM climate dataset (https://worldclim.org; Fick & Hijmans, 2017). These variables were derived from monthly average climate data (maximum and minimum temperature, and total precipitation) recorded between 1970 and 2000, which were obtained from a global network of weather stations (Fick & Hijmans, 2017). In addition, a Digital Elevation Model based on data from the Shuttle Radar Topographic Mission (SRTM) was used. All predictor variables at a spatial resolution of 30 arc seconds (~1 km^2 grid resolution) were used (Table 1).

3.3.2.2 Global horizontal irradiance

The sensitivity of plants' photosynthetic apparatus to various wavelengths of radiation varies among different plant species (Rabinowitch 1951 as cited in McCree, 1981). The irradiance spectrum has specific effects on different types of plant responses such as photosynthesis, photo morphogenesis, phototropism, and photonasty which ultimately results in size and biomass accumulation (Hogewoning *et al.*, 2010). Global horizontal irradiance (https://globalsolaratlas/support/data-outputs, World Bank Group, 2019) which is the sum of direct normal irradiance, diffuse horizontal irradiance, and ground-reflected radiation on a horizontal surface is also used as predictor variable.

3.3.2.3 Human influence index

The Human Influence Index (https://sedac.ciesin.columbia.edu/data/set/wildareas-v2-human influence-index-geographic, WCS & CEISIN, 2005) provides valuable information on areas where human activities are causing pressures on natural systems, resulting in their deviation from their natural states. The values range from 0 to 64, where 0 represents no human influence and 64 represents maximum human influence. It comprises remotely-sensed and bottom-up survey information on different eight variables related to human influence measuring the direct and indirect human pressures on the environment. The analysis of pressures on ecosystems not only identifies areas that require protection or restoration but also highlights places where ecosystems operate naturally.

This understanding of pressure distribution can help in the identification of priority areas for ecosystem conservation. Moreover, the knowledge of the spatial distribution of pressures can provide valuable insights into macro-ecological patterns (Venter *et al.*, 2016).

3.3.2.4 Cloud cover

Cloud cover (https://www.earthenv.org/cloud.html) has an impact on various vital ecological processes, which comprise reproduction, growth, survival, and behavior (Wilson & Jetz, 2016). Fine scaled remotely sensed cloud climatology has improved the predictive accuracy of species distribution without inflating autocorrelation. The values of cloud cover range from 0-10,000 but it needs to be multiplied by 0.01 to get percentage of cloudy days. As Southeast Asia being one of the cloudiest regions of the world (Wilson & Jetz, 2016), the cloud cover is used as predictor variable.

Table 1: List of predictor variables used

Abbreviation	**Variables name**	**Unit**	Source
WC01	Annual Mean Temperature	°C	Fick & Hijmans, 2017
WC02	Mean Diurnal Range (Mean of monthly (max temp - min temp))	°C	Fick & Hijmans, 2017
WC03	Isothermality (WC02/WC07) (* 100)	Percentage	Fick & Hijmans, 2017
WC04	Temperature Seasonality (standard deviation *100)	°C	Fick & Hijmans, 2017
WC05	Max Temperature of Warmest Month	°C	Fick & Hijmans, 2017
WC06	Min Temperature of Coldest Month	°C	Fick & Hijmans, 2017
WC07	Temperature Annual Range (WC05 – WC06)	°C	Fick & Hijmans, 2017
WC08	Mean Temperature of Wettest Quarter	°C	Fick & Hijmans, 2017
WC09	Mean Temperature of Driest Quarter	°C	Fick & Hijmans, 2017
WC10	Mean Temperature of Warmest Quarter	°C	Fick & Hijmans, 2017
WC11	Mean Temperature of Coldest Quarter	°C	Fick & Hijmans, 2017
WC12	Annual Precipitation	mm	Fick & Hijmans, 2017
WC13	Precipitation of Wettest Month	mm	Fick & Hijmans, 2017
WC14	Precipitation of Driest Month	mm	Fick & Hijmans, 2017
WC15	Precipitation Seasonality (Coefficient of Variation)	-	Fick & Hijmans, 2017
WC16	Precipitation of Wettest Quarter	mm	Fick & Hijmans, 2017
WC17	Precipitation of Driest Quarter	mm	Fick & Hijmans, 2017
WC18	Precipitation of Warmest Quarter	mm	Fick & Hijmans, 2017
WC19	Precipitation of Coldest Quarter	mm	Fick & Hijmans, 2017
-	Global Horizontal Irradiation	kWh/m^2	World Bank Group, 2019
-	Human Influence Index	-	WCS & CIESIN, 2005
-	Cloud Cover	-	Wilson & Jetz, 2016

3.3.3 Bias correction

The information on species locality typically includes records from various sources such as museums, herbaria, university databases, or field work. These records are often compiled from different surveys that are designed with different objectives in mind because of which some areas may be overrepresented while others may be underrepresented which can lead to sampling biases. And as a result, biased data produces poor predictions (Elith, 2006; Beck *et al.*, 2014). Despite these biases, it still better to utilize those accumulated data but with correction. Basically, there are three types of sampling bias correction methods; target background (Philips *et al.*, 2009), geographic filtering and environmental filtering (specifically, a climatic filter). Geographic filtering has been used more often as a tool to improve SDMs (Rana *et al.*, 2019, Paudeyal *et al.*, 2021) while environmental filtering is less explored. Models made with environmental filtering have been found to perform better than those made with geographic filtering (Varela *et al.* 2014, Fourcade, 2014). For the same dataset, it has consistently resulted in better, improved models with higher AUC than geographic filtering (Varela *et al.*, 2014). For environmental filtering, we thinned down the multidimensional environmental space by condensing the predictors to two axes using principal component analysis. Then space was divided into cells and just one record in each cell was randomly chosen to represent the species. Such thinned records more evenly represent the conditions experienced by the species within its range.

3.3.4 Selection of variables

The collinearity among the predictor variables gives poor model performance and misleading interpretations (Dormann *et al.*, 2013). When a large set of predictor variables are considered for analysis, the model complexity increases and may lead to the development of heavily parameterized and over fitted models (Merow *et al.*, 2014). So, the variables should be examined for possible correlations and eliminate highly correlated variables (Sillero & Barbosa, 2021). At first, predictor variables at the species' occurrence were extracted and then spearman's rank correlations were calculated using the R-programming language (R Core Team, 2022) to detect multi-collinearity among the variables. For better visualization and understanding of the correlation between variables, spoke plot was created using R package 'legendary' (Smith, 2021) which draws lines between variables if they are correlated as defined by a given correlation coefficient threshold. From the spoke plot, the variables that were not strongly correlated with another variable were retained. Regarding the correlated variables, only ecologically meaningful variables, which represent the general pattern and annual variability of the climate, were included for modelling the potential distribution of *Swertia* species. The threshold of Spearman's rank correlation coefficient $r_s \leq 0.7$ (Elith *et al.*, 2006) was used to detect the multicollinearity.

3.3.5 Model building / Model algorithm

Several methods are available for constructing SDMs and they have been comprehensively compared in terms of performance (Elith, 2011; Zhu & Peterson, 2019). For the presence only data, 'Maxent' (Phillips, 2006; Elith *et al.*, 2011) has become the gold standard for correlative SDMs development. It is a general-purpose machine learning program that has the capacity to model complex relationships and interactions with excellent predictive ability (Elith & Graham, 2009) even with the small sample size (Weiz *et al.*, 2008) and is considered one of the most efficient approaches to SDM using presence only data (Elith *et al.*, 2011).

Maxent uses a set of known occurrences of the species in combination with environmental variables and predict the suitability of the environment for the species. The goal of the Maxent method is to identify the probability distribution with maximum entropy while taking into account both the observed distribution of species and the environmental conditions. It assigns a non-negative probability to all pixels in the study area (Phillips, 2006). For our study, we have used R packages, 'dismo' (Hijmans *et al.*, 2021) and 'maxnet' (Philips, 2021) for model prediction. 'maxnet' is the R version of Maxent Java application released in 2017 (Philips, 2017) which uses the same feature classes (linear, quadratic, hinge, etc.) and regularization options as the Java version. Besides that, for the spatial data analysis R packages; 'raster' (Hijmans, 2022a) and 'terra' (Hijmans, 2022b) have been used.

3.3.6 Model validation

To obtain a more accurate measure of performance, a cross-validation procedure is utilized, where separate test data is used. This procedure involves dividing the data into a number of folds, with each fold used to test the model. The presence data is divided into exclusive groups or "folds," usually comprising around 20% of the data set (Bobrowski *et* *al.*, 2021). The model is then trained using all the presences, except for one group, which is used to test the model's performance using specific measures. Finally, the model's performance is averaged across groups, which presumably provide a better indication of its ability to predict new data. For this, geographic cross-validation was used instead of the most commonly used random cross-validation (Ranjitkar *et al.*, 2014; Paudeyal *et al.*, 2021). The advantage of partitioning the data into geographic folds over random partitioning is that test data are spatially more distant from training data, increasing independence and thus increasing the reliability of the evaluation metric (Roberts *et al.*, 2017; Valavi *et al.*, 2019; Hao *et al.*, 2020). This involves partitioning the data into mutually exclusive spatial blocks or geographic folds, which are used to validate models. The occurrence data is divided into three geographic folds and used for validation using R package ‘enmSdm’ (Smith, 2022).

3.3.7 Model evaluation

The accuracy of the prediction models was evaluated using the receiver-operating characteristics area under the curve (AUC) method, which is not dependent on a particular threshold (Liu *et al.*, 2005; Phillips *et al.*, 2008; Liu *et al.*, 2016). It constitutes a measure of overall model performance irrespective of threshold. The AUC is a non-parametric measure and varies according to the suitability proportion of the study region. It is one of the most widely used threshold-independent evaluators of model discriminatory power and has become commonly used metric for evaluating the accuracy of models predicting distributions of species and has the advantage of being threshold independent (Warren, 2011). AUC represents the probability that a randomly drawn presence site has a higher predicted value than a randomly drawn background site and evaluates how well model predictions discriminate between locations where observations are present or absent.

The AUC values have a scale ranging from 0 to 1, where a higher score indicates that there is a higher probability of a presence (Elith et al., 2006; Phillips et al., 2006). The AUC values produced by each model were used to determine if they were significantly better than random AUC (0.5). The AUC values of > 0.9 are considered high, 0.7-0.9 moderate, 0.5-0.7 low and < 0.5 no better than random (Wiley *et al.*, 2003; Phillips *et al.*, 2006).

3.3.8 Future projection

To investigate the potential impact of climate change on species distribution, the current relationship between species and climate was projected onto future climate predictions.

The suitability of the species was then evaluated by converting the probability of occurrence predicted by the model into suitability maps. The probability of occurrence values is typically reported on a scale of 0 to 1, where 0 represents a low probability of occurrence, and 1 represents a high probability of occurrence. The suitable and unsuitable conditions were then reclassified as ≥ 0.5 suitable and < 0.5 as unsuitable.

For future climatic projections related to climate change, HadGEM2-ES (Hadley Centre Global Environment Model version 2), a global circulation model (GCM) submitted for Coupled Model Inter-comparison Project Phase 5 (CMIP5) was used. HadGEM2-ES is considered to have higher capabilities to reproduce spatial patterns of the mean and inter annual variability of monsoon precipitation across the Himalayas (Kadel *et al.*, 2018). Future climatic projections for both time periods were also obtained from the WORLDCLIM climate dataset (https://worldclim.org; Fick & Hijmans, 2017).

The suitability is predicted in two different future periods (2050 and 2070) using two different Representative Concentration Pathways RCP 6 and RCP 8.5. Representative concentration pathways (RCPs) are series of pathways that illustrates greenhouse gas concentration and emissions which are designed to support research on the impacts of and potential policy responses to climate change (Moss *et al.*, 2010; Riahi *et al.*, 2011; van Vuuren *et al.*, 2011). Four Representative Concentration Pathways (RCPs) based on the emissions of greenhouse gases were adopted by the IPCC for future climate projections in its fifth assessment report in 2014. Of those, RCP 6 and RCP 8.5 were used in our study. In RCP 6, emissions peak around 2080 with 6 kWh/m^2 radiating force of greenhouse gases and then decline and stabilize by 2100. In RCP 8.5, emissions continue to rise throughout the 21st century with a value of 8.5 kWh/m^2 radiating force of greenhouse gases. RCP 8.5 leads to much greater temperature increases with greater impacts and greater costs (IPCC, 2014).

3.4 Population Ecology of *Swertia multicaulis*

3.4.1 Identification of study population and sampling design

For ecological study of *S. multicaulis*, field studies were conducted during the peak growing season (August/September) in 2019 around Gosainkunda area in the Lamtang National Park. Preliminary participatory resource mapping was done prior to the field observation to locate the potential habitats of *S. multicaulis*. Then a resource map was prepared with the help of herders and hotel owners. Based on the information from the field survey, a total of four sites were identified for the population study, which were completely differentiated from each other by geographical barriers. The four population sites are abbreviated as LA_1 (around Buddha Mandir area), LA_2 (near Gosainkunda View Point) and HA_1 (near Suryakunda), HA_2 (near Dudhkunda). HA_1 and HA_2 both are at higher elevations, while LA_1 and LA_2 are at lower elevations.

For the sampling, a total of 40 sampling plots, each of 3m × 3m were laid down with minimum of 15-20 m plot to plot distance. In each population site, 3 m^2 plot was repeated 10 times. Each plot was further divided into nine 1m × 1m sub-plots. Out of nine sub-plots, four corner ones and one central were used for the population sampling (Figure 4). Thus, a total of 200 sub-plots were studied in this research.

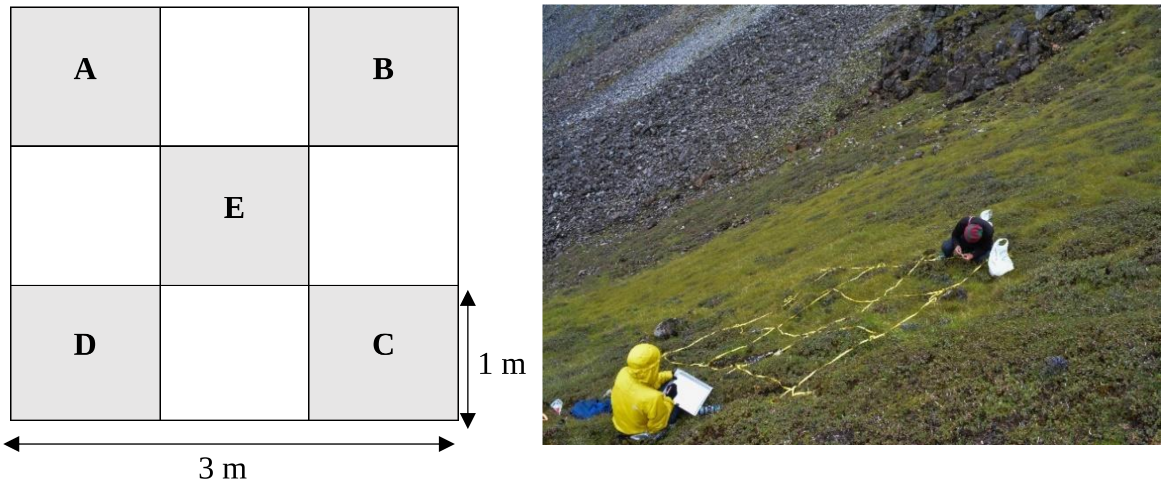

Figure 4: Diagrammatic representation of 3m × 3m plot for sampling with nine 1m × 1m sub-plots

3.4.2 Variation in population density and structure

Population density and the structure of *S. multicaulis* were studied in each of the populations. Density was measured as the total number of individual plants in a 1 m^2 sub-plot. On the basis of number and size of leaves and occurrence of reproductive parts, each individual plant was classified into four stage categories; a) young plant (up to 8 leaves), b) juvenile (with 9-19 leaves), adult vegetative (with 20 or more leaves but not flowering) and d) adult reproductive (with 20 or more leaves with flowers or fruits). The juvenile category was further classified into three sub-categories; juvenile 1 (with 9-12 leaves), juvenile 2 (with 13-16 leaves) and juvenile 3 (with 17-19 leaves). During the population sampling, number of individual plants at different life staged categories were recorded in every sub-plot (Figure 4).

3.4.3 Variation in growth strategy and plant performance

The variation in growth strategy and plant performance was studied in all populations. In each population, every single plant was measured for the vegetative (number of leaves, leaf size and rosette diameter) and reproductive (number of flowers, florescence length and number of fruits) traits (Table 11). For the measurement of leaf size, two largest leaves at the base were measured. To better understand plant growth and resource acquisition, the leaf dry matter content (LDMC) was calculated, which is the ratio of the dry weight of the leaf to its fresh weight. LDMC denotes the leaf water content, which corresponds to the leaf content in mesophyll tissues (Pescador *et al.*, 2015).

The biomass allocation pattern was assessed to determine the relative contributions of vegetative and sexual reproduction. In each population, ten mature individuals were selected for harvesting the different plant parts (rhizome, above ground shoots with leaves and inflorescence). The plant parts were cleaned, air dried and weighted. After that it was brought to the laboratory and dried in an oven at 80°C for 48 hours. The oven dried plant parts were separately measured to obtain and the following parameters: sexual allocation (dry biomass of inflorescence), sexual reproductive effort (dry biomass of inflorescence/total dry biomass), above ground vegetative allocation (dry biomass of vegetative shoot), above ground vegetative effort (dry biomass of vegetative shoot/total dry biomass), below ground allocation (dry biomass of root), below ground vegetative effort (dry biomass of root /total dry biomass).

3.4.4 Measurement of bio-physical parameters

As biophysical parameters in each sub-plot, slope, aspect, elevation, surface cover by vascular or non-vascular plants, litter/rock/bare-ground cover and distance from the nearest trail/settlement were recorded (Table 8). The surface area cover was estimated by visual method. Latitude, longitude and elevation were taken at the center of $3m^2$ plot with the help of a GPS device. Similarly, slope and aspect were recorded with the help of a clinometer and a compass. The values of slope, aspect and latitude were combined to estimate the relative radiation index (RRI), which gives the relative value of how much solar radiation a particular spot receives at noon at equinox. The RRI value ranges from +1 to -1 and was calculated using the following formula (Ôke, 1987):

$RRI = \cos(180°-\Omega).\ \sin\beta.\sin\theta + \cos\beta.\ \cos\theta$ (where, Ω is aspect, β is the slope and θ is the latitude)

For the calculation of RRI the aspect was rescaled from 0-360° to 1-180° by using the formula;

Folded Aspect = 180 -|Aspect-180| (McCune, 2007)

Soil organic carbon (SOC) and soil pH were analyzed in laboratory. Soil samples were collected from each 1 m^2 sub-plot and then mixed and packed in Ziplock bags. So, each sample represent a soil sample for each 3 m^2 plot. The soil samples were brought to the laboratory and air dried in the shade for two weeks for further analysis. For the soil pH, the potentiometric titration method was used and for the SOC, Walkley-Black (Walkley & Black, 1934) method was used.

3.4.5 Analysis of ecological data

The data were first tested for normality using the Shapiro-Wilk test Upon revealing the non-parametric distribution, Kruskall-Wallis test was applied to detect any difference. When Kruscal-Wallis test detected a significant difference, Dunn's test was used for multiple comparisons. The R package, 'dunn.test' (Dinno, 2017) with Bonferroni correction, was used for multiple pairwise comparison. The Spearman rank correlation coefficient was also obtained to assess the relationship between environmental variables. As biomass allocation also showed a non-parametric distribution, the Kruskall-Wallis test was used to examine the variation.

To detect the relationship between the plant density in different life-stage categories and the environmental variables, generalized linear mixed effects model was used. A poison distribution of the response variable (i.e., density) was assumed since it did not meet standard statistical assumptions of normality. To quantify the relationship, different models were built using 'lme4' package (Bates *et al.*, 2015) in R Studio version 4.1.3 (R Core Team, 2022). The primary model was prepared with all the environmental variables included as fix effects and plot as random effect after removing the highly correlated variables. Then, to identify which variables are most crucial in explaining the effects on response variable, a ranked list of candidate models based on the Akaike Information Criterion (AIC) was created using the dredge() function in the package 'MuMin' (Bartoń, 2020). The model with the low AIC value was used for further analysis. The AIC value was calculated for each model and compared with the null model (without fix effects) to assess the validity.

CHAPTER IV: RESULTS

4.2 Species Distribution Modelling

4.2.1 Bias correction of presence records

The bias correction based on the PCA, using the environmental variables at the presence records of the species reduced the number of presence records for each species. It was done after the removal of all duplicate records from the original dataset, keeping one record per cell. Finally, the number of presence records of *S. alata was* reduced from 21 to 15. Similarly, for *S. angustifolia* from 43 to 24, *S. ciliata* from 32 to 20*, S.dilatata* from 31 to 25*, S. multicaulis* from 140 to 41*, S. racemosa* from 43 to 21 and for *S. nervosa* from 34 to 20 (Figure 5). These records utilized for subsequent analysis in the process of selecting predictive variables and running the model.

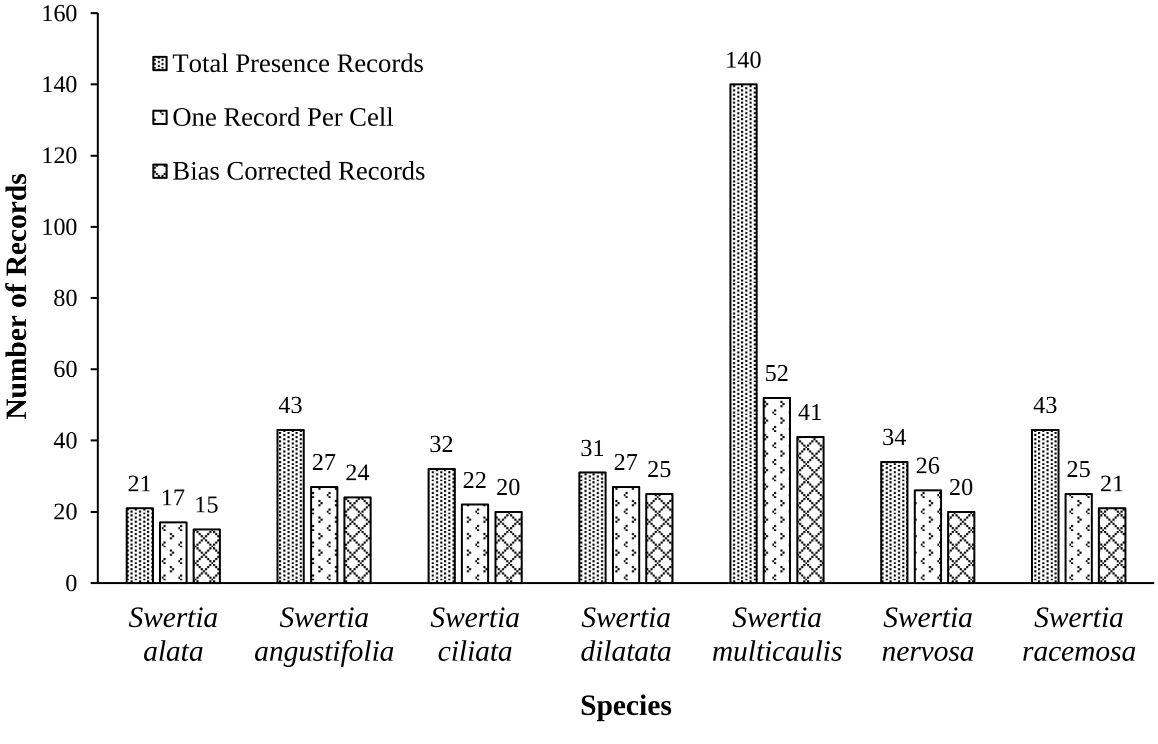

Figure 5: Occurrence records of *Swertia* species

4.2.2 Model evaluation

The AUC values obtained from the geographic fold cross validation indicated the accuracy of model prediction. The AUC of all of the species is more than 0.5 (Table 2) which indicates that they are better than random prediction.

Table 2: AUC values for different *Swertia* species

Species	*Swertia alata*	*Swertia angustifolia*	*Swertia ciliata*	*Swertia dilatata*	*Swertia multicaulis*	*Swertia racemosa*	*Swertia nervosa*
AUC	0.63	0.78	0.71	0.82	0.93	0.79	0.75

4.2.3 Selected climatic variables and their contribution

With the help Spearman's rank correlation coefficient and the spoke plot, a set of six to eight species-specific least correlated predictive variables were chosen for projecting the spatial distribution model for each of the *Swertia* species (Table 3). For all of the species, global horizontal irradiance and annual mean temperature along with Cloud Cover were the most common variables selected. Out of seven *Swertia* species, six predictor variables were used for *S. angustifolia, S. racemosa* and *S. dilatata*. For *S. ciliata*, eight variables were used and for rest of three species seven variables were used to predict the distribution.

In each set of selected variables for the modelling, each individual variable has a different contribution value to the model prediction (Appendix 1). Annual temperature range and annual mean temperature were the most influential variable for the prediction of *S. alata* with 43.27% and 19.31% contribution followed by global horizontal irradiance and human influence index respectively (Appendix 1a). For *S. angustifolia,* annual precipitation and annual temperature range were the most influential predictors contributing 41.93% and 38.52% respectively in model prediction (Appendix 1b).

Out of 8 predictors for distribution of *S. ciliata,* precipitation of driest month contributed the most to model prediction with 40.55% followed by annual mean temperature with 22.96% and global horizontal irradiance with 11.04% respectively (Appendix 1c). More significant predictors for *S. dilatata* were annual temperature range with 52.23% contribution and isothermality with 20.13% contribution along with annual mean temperature with 12.56% contribution (Appendix 1d).

Precipitation of driest month and annual mean temperature were key variables for predicting the distribution of *S. multicaulis*. Both predictors contributed more than 65% (Appendix 1e). For *S. nervosa*, temperature seasonality, annual mean temperature and isothermality contributed more with 36.83%, 24.79% and 17.61% respectively of total variables (Appendix 1f). And finally for *S. racemosa,* precipitation of coldest quarter with 41.36% and precipitation of driest month with 34.23% contribution were the most influential predictors (Appendix 1g).

Table 3: Set of selected variables for different species of *Swertia*

Species	*Swertia alata*	*Swertia angustifolia*	*Swertia ciliata*	*Swertia dilatata*	*Swertia multicaulis*	*Swertia nervosa*	*Swertia racemosa*
Predictor Variables	Cloud cover	Cloud cover	Cloud cover	Cloud cover	Cloud cover	Cloud cover	Global horizontal irradiance
	Global horizontal irradiance	Global horizontal irradiance	Global horizontal irradiance	Global horizontal irradiance	Global horizontal irradiance	Global horizontal irradiance	Human influence index
	Human influence index	Human influence index	Human influence index	Human influence index	Human influence index	Annual mean temperature	Annual mean temperature
	Annual mean temperature	Annual mean temperature	Annual mean temperature	Annual mean temperature	Annual mean temperature	Mean diurnal range	Mean diurnal range
	Mean diurnal range	Isothermality	Isothermality	Isothermality	Isothermality	Isothermality	Precipitation of driest month
	Isothermality	Temperature annual range	Temperature seasonality	Temperature annual range	Temperature annual range	Temperature seasonality	Precipitation of coldest quarter
	Temperature annual range		Precipitation of driest month		Precipitation of driest month	Temperature annual range	
			Precipitation of driest quarter				

4.2.5 Response curves of predictor variables

Response curves show the relationship between the probability of occurrence for a species and each of the predictor variables. In each response curve, the response is modelled for one variable while holding the other variables constant at their mean. This illustrates the impact of each variable on the Maxent prediction. In the response curves, x-axis represents the range of values of the environmental variable, and the y-axis gives the probability of occurrence on a scale from 0 (low probability) to 1 (high probability).

Appendices 2-8 represents response curves of Maxent model for all of *Swertia* species. Results derived from curves showed that the probability of the presence decreased with the increase in annual temperature range above ≈ 20°C for *S. alata* (Appendix 2). Mean annual temperature between -5 °C to 15 °C is found to be suitable for occurrence. Similarly, less than 3 kWh/m^2 of global horizontal irradiance favored in probability of species occurrence. Rest of the variables had less contribution in the model.

Mean annual temperature and annual temperature range were the main contributing variable for *S. angustifolia* (Appendix 1b). Probability of presence decreased above 14-15

°C of mean annual temperature and 20 °C above annual temperature range (Appendix 3). In the case of *S. ciliata*, an increase in both the precipitation of the driest month and the precipitation of the driest quarter indicated higher probability of presence but abruptly decreased beyond ≈10 °C of mean annual temperature (Appendix 4). In case of *S.dilatata,* isothermality exhibited a positive relationship with probability of occurrence, whereas annual temperature range had the reverse relationship (Appendix 5). For *S. multicaulis,* the probability of occurrence peaked around -5° to -6 °C of mean annual temperature and more than 5 mm of precipitation of the driest quarter (Appendix 6). But for *S. nervosa,* the probability of occurrence peaked around 15 °C of mean annual temperature (Appendix 7). In the case of *S. racemosa,* the precipitation of coldest quarter and the precipitation of driest month were more contributing variables in the model (Appendix 8). Around 125 mm of precipitation of the coldest quarter showed a peak of probability of presence. Similar to this, the probability of a species' occurrence increased when more than 5 mm of precipitation during the driest month.

4.2.6 Potential suitable area under current climate

The predicted models of each of the *Swertia* species predicted their potential distribution range in the mountains and alpine regions (Appendix 9-15) of Nepal under current climatic conditions (1970-2000). Appendices 16-21 represents district wise potentially suitable area for all of *Swertia* species. Total potential suitable area under current climate is in Table 4.

The estimated suitable habitat for *S. alata* is predicted mostly in the hills and middle mountains of Province 1, Bagmati, Gandaki and Karnali provinces (Appendix 9 & 16b). The total suitable area predicted for *S. alata* covered 52561.78 km^2 which is 35.5% of total area of the country. Karnali province was found to be the largest province to cover suitable habitat of 30717.91 km^2 (ca. 20.78% of the total area of Nepal) and Sankhuwasabha district had the highest suitable area of 2506.21 km^2 (Appendix 16). The uphills of Sudurpashim province showed dispersed distribution pattern. The several isolated patches of small size also occurred throughout Siwalik range. The model predicted the Madhesh province and rest of Tarai region as not suitable areas for *S. alata*.

The overall predicted suitable area for *S. angustifolia* was 31051.41 km^2, or roughly 20.97% of the entire area of the country, primarily in the hills of Province 1, Bagmati and Gandaki provinces (Appendix 10 & 17). Small patches of suitability were found in the

Siwalik range of Sudurpaschim province. Comparatively, the western and central region exhibited more suitable area than the eastern region. Karnali and Gandaki showed more suitability covering 18231.9 km^2 and 10112.31 km^2 respectively (Appendix 17b). However, in terms of districts covering the suitable area, Sankhuwasabha (1730.52 km^2) of Province 1 and Sindhupalchok (1630.16 km^2) of Bagmati province were found to be the first and second largest districts with suitable areas for *S. angustifolia* (Appendix 17a). The model indicated that *S. ciliata* would be more suitable in the western region. More suitable provinces were in Karnali (20788.18 km^2), Gandaki (15478.43 km^2) and Bagmati (5232.54 km^2). Total suitable area covered was 32066.78 km^2 which accounts for 21.66% of the total area of the country. Large suitable areas were found in districts like Jumla (2174.86 km^2), Dolpa (2044.35 km^2) and Solukhumbu (2031.78 km^2) (Appendix 18).

Predicted suitable habitat for *S. dilatata* covers 10.92% of the total land cover which is 16172.17 km^2. Province 1 was found to be the most suitable province for *S. dilatata* covering 8530.25 km^2 of total suitable area (ca. 5.76% of the total area) (Appendix 12 & 19). Despite having inadequate records from the western part of the country, the model shows suitability in the Karnali and Sudurpaschim provinces as well. Karnali province showed 7323.45 km^2 and Sudurpaschim 99.55 km^2 of suitable area. Sankhuwasabha, Solukhumbu and Taplejung were found to be the top three large districts in terms of having suitable areas for *S. dilatata* (Appendix 19).

For *S. multicaulis*, the model predicted the alpine regions of Province 1, Bagmati and Gandaki to be more suitable area (Appendix 13 & 20). Suitable habitat covered an area of only 2.62% of the total land cover which is 3869.06 km^2. Small patches in the high alpine areas of Karnali and Sudurpaschim provinces were also found suitable for *S. multicaulis* although no official records have been reported before from these regions. *S. racemosa* showed suitable area of 32003.49 km^2 (ca. 21.61% of total area) in mountains from east to west Nepal. Karnali (21402.16 km^2), Gandaki (18145.01 km^2), and Province 1 (5807.57 km^2) provinces were projected to be more suitable (Appendix 20b). With a total area of 4132.63 km^2, Dolpa was found to be the best district for *S. racemosa* (Appendix 22a). *S. nervosa* also showed suitability in the mid hills and mountains from east to west Nepal mostly in Karnali province with 23038.9 km^2 of total suitable area (ca. 15.56% of total area). The model also predicted some part of provinces of Gandaki and Bagmati would be suitable (Appendix 21b). Total suitable area predicted for *S. nervosa* was 45569.49 km^2 which is 30.76% of the total land. Although, Karnali province had the largest suitable area covered, districts of Province 1, Sankhuwasabha (1911.77 km^2), Solukhumbu (1874.36 km^2) and Taplejung (1801.29 km^2) were the largest districts covering suitable area (Appendix 21).

4.2.7 Potential suitable area covered by protected areas

Appendices 23-29 represents potentially suitable area inside different protected areas of Nepal for all of *Swertia* species under current climate. In terms of having a more favorable location, Makalu-Barun NP and Sagarmatha NP were significant for the majority of the *Swertia* species in the eastern region. Form central region, Gaurishanker CA, Annapurna CA, and from the western region Api-Nampa CA, Dhorpatana HR and Shey-Phoksundo NP were important PAs for suitable habitat for *Swertia* species.

The lowest suitable area covered by PAs within the country was for *S. multicaulis* which was only 3051.08 km^2 (ca. 2.06% of total area). The estimated area accounted for 78.86% of the area covered within PAs, implying that *S. multicaulis* had the majority of the predicted suitable area within PAs and only 21.14% outside of them. For *S. multicaulis,* the PAs from the central to eastern regions covered more suitable areas than those from the western region. Gaurishanker CA had the highest suitable area of 692.35 km^2 followed by Makalu-Barun NP and Sagarmatha NP with 578.58 km^2 and 558.67 km^2 respectively (Appendix 23).

S. racemosa had the highest suitable area covered by PAs which was 15444.68 km^2 (10.43% of total area within the country). Despite having the highest suitable area covered among the *Swertia* species, it only has 48.26% of its territory covered by PAs, with the rest being outside of PAs. Gauishanker CA had the highest suitable area which was 4319.77 km^2 followed by Annapurna CA and Shey-Phoksundo NP with 1622.52 km^2 and 1612.08 km^2 respectively (Appendix 29).

Table 4: Potential suitable area covered by Protected Areas under current climate

***Swertia* Species**	**Suitable area (km^2) under current climate**	**Suitable area (km^2) covered by PAs only**	**Suitable area covered by PAs (%)**	**Suitable area covered by PAs with Nepal's Area (%)**
S. alata	30717.91	10629.89	34.6	7.18
S. angustifolia	31051.41	10340.16	19.19	4.2
S. ciliata	32066.78	7405.61	32.25	6.98

S. dilatata	16172.17	5959.98	27.13	2.96
S. multicaulis	3869.06	3051.08	78.86	2.06
S. nervosa	45569.49	8707.72	19.11	5.88
S. racemosa	32003.49	15444.68	34.6	10.43

4.2.8 Potential distribution in future

The Global Circulation Model HadGEM2- ES was used to assess habitat suitability in future climatic scenarios for two different Representative Concentration Pathways; RCP 6 and RCP 8.5. The changes in the area of potential suitability vary among the *Swertia* species in future climatic scenarios (Appendices 22-28). For all of the *Swertia* species, the overall suitable habitat has declined significantly in both RCP scenarios, except for *S. racemosa* which had slightly decreased suitability in 2050 but increased in 2070. Although a good potential suitability is predicted under the current climate for three of the species, *S. angustifolia, S. dilatata* and *S. nervosa*, the models did not reveal any suitable area over our defined threshold in either of the future climate scenarios.

4.2.8.1 Future potential distribution in RCP 6

In the RCP 6 future scenario, models for all the species predicted decreased suitability compared to the current climatic scenario. *S. angustifolia, S. dilatata* and *S. nervosa* did not have any suitable areas better than our threshold value available in 2050 and 2070 (Table 5).

For *S. alata*, the model predicted only 1649.28 km^2 and 1054.88 km^2 for 2050 and 2070 which decreased from 35.50% to 1.11% in 2050 and 0.71% in 2070 of total land cover respectively. The predicted model showed more suitable areas in the mountains of Gandaki and Karnali provinces in future. Gandaki province showed the highest suitability in 2050 (934.69 km^2) and 2070 (591.94 km^2) (Appendix 16b), but under current climate Karnali province had shown highest suitability. Humla, Kathmandu and Mugu districts showed more suitability in 2050 and 2070 (Appendix 16a). Rolpa, Salyan, and Dailekh districts are expected to be unsuitable in the future. All together in 39 districts is predicted as not suitable in the future climate scenarios in 2050.

Models predicted, decreased suitability for *S. ciliata* in 2050 and 2070 with 16254.71 km^2 and 11831.48 km^2 of suitable area respectively. Karnali province was predicted to have the largest suitable area under the current climate but in 2050 and 2070 models predicted

Gandaki province to have more suitable area (Appendix 18). In the districts like Jumla, Humla and Mugu the suitability has been found to be increased in the future (Appendix 18a).

A very small area is predicted suitable for *S. multicaulis* under the current climate which again decreased in 2050 and 2070 with 499.09 km^2 and 289.57 km^2 respectively. Suitable area in future is shifting more in the north-west alpine regions of Gandaki and Karnali, Sudurpaschim provinces but disappearing from the eastern alpine region (Appendix 13 & 20b). In future climate scenarios, districts form Karnali and Sudurpaschim provinces like Humla, Bajhang, Darchula, Mugu showed suitability even though no suitable places were detected under current climate (Appendix 20).

In contrast to the rest of the species, future models of *S. racemosa* showed a different pattern. In 2050, suitability is predicted to be slightly decreased than predicted in current climate which was 28203.88 km^2 (ca. 19.05% of the total area). However, a minor expansion of potential habitat in high mountains across the country is predicted in 2070. In 2070, the suitable habitat increased to 30788.93 km^2 which is 20.79% of the total area. Suitability is marginally reduced in Karnali province but increased in the remaining provinces except Madhesh. In 2050 and 2070 Humla district showed the highest suitability of 3885.24 km^2 and 4465.38 km^2 which has increased from 2776.18 km^2 predicted under current suitable area (Appendix 22).

4.2.8.2 Future potential distribution in RCP 8.5

Except for *S. racemosa*, future climatic scenarios based on RCP 8.5 predicted significantly reduced suitable habitat in 2050 and 2070 for all *Swertia* species (Table 5). For *S. angustifolia, S. dilatata, S. multicaulis,* and *S. nervosa*, no suitable habitat was found beyond the defined threshold.

Suitable habitat for *S. alata* reduced from 52561.78 km^2 to 1134.81 km^2 to 594.04 km^2 in 2050 and 2070 respectively. Karnali and Gandaki provinces will have more suitable areas in the future (Appendix 9 & 16b). Suitability for *S. ciliata* decreased from 32066.78 km^2 to 11782.87 km^2 in 2050 and to 8093.91 km^2 in 2070 respectively. Gandaki and Karnali provinces are predicted to have more suitability in the future (Appendix 18b). Humla is expected to be the largest district in terms of area, with 2769.38 km^2 and 1987.64 km^2 of suitable area in 2050 and 2070 respectively (Appendix 18).

For *S. racemosa*, however, predicted suitable a favorable climate will exist in the future. In 2050, the suitable area was 30427.26 km^2, a slight decrease from 32003.39 km^2, but in 2070, it had increased to 31264.31 km^2. The most suitable regions for growth are in the high mountains of the Gandaki and Karnali provinces (Appendix 22b). Most of the expected growth will occur in the districts of Humla, Taplejung, and Gorkha (Appendix 22).

Table 5: Potential suitable area under current and future climate (2050 and 2070 in both RCP 6 and RCP 8.5)

***Swertia* Species**	**Suitable area (km^2) under current climate**	**RCP 6**		**RCP 8.5**	
		Suitable area (km^2) in 2050	**Suitable area (km^2) in 2070**	**Suitable area (km^2) in 2050**	**Suitable area (km^2) in 2070**
S. alata	30717.91	1649.29	1054.89	1134.82	594.04
S. angustifolia	31051.41	-	-	-	-
S. ciliata	32066.78	16254.71	11831.48	11782.87	8093.91
S. dilatata	16172.17	-	-	-	-
S. multicaulis	3869.06	499.09	289.58	-	-
S. nervosa	45569.49	-	-	-	-
S. racemosa	32003.49	28203.88	30778.93	30427.26	31264.31

4.2.9 Potential suitable elevation under current and future climate

In future climatic scenarios, models predicted an increase in elevation range for all *Swertia* species. In both RCPs, the models predicted the shifting of *Swertia* species towards a higher elevation range in both future time periods from the current suitable average elevation (Table 6). In RCP 8.5, the elevation range increased more than in RCP 6. The average suitable elevation range for the species is found to be between 2000-3000 m except for *S. multicaulis* and *S. racemosa* which were 3942 m and 4330 m. In 2050 and 2070, no suitable elevation range for *S. angustifolia*, *S. dilatata* and *S. nervosa* is predicted as these species did not show any suitability in future climate.

Among the species that exhibited future climatic adaptability, *S. multicaulis* had the highest predicted average elevation rise of 882 m. The average suitable elevation under the current climate was 4330 m, which increased to 5212 m in 2050 and again to 5390 m in 2070 under RCP 6. However, in RCP 8.5 no suitability is detected. *S. racemosa* is expected to have the lowest average suitable elevation rise in future. The average predicted elevation is found to be 3919 m in 2050 RCP 6 which has increased from 3568 m and in 2070 it became 4026 m gaining 107 m of average elevation than 2050. RCP 8.5 has a similar pattern in both future time periods. In RCP 8.5 an average elevation of 4025 m is predicted in 2050, rising to 4169 m in 2070.

Table 6: Potential suitable elevation (masl) of *Swertia* species under current and future climate (2050 and 2070 in both RCP 6 and RCP 8.5)

***Swertia* Species**	**Average suitable elevation (m.) under current climate**	**RCP 6**		**RCP 8.5**	
		Average suitable elevation (m.) in 2050	**Average suitable elevation (m.) in 2070**	**Average suitable elevation (m.) in 2050**	**Average suitable elevation (m.) in 2070**
S. alata	2125	2785	2874	2875	2993
S. angustifolia	2165	-	-	-	-
S. ciliata	2918	3521	3656	3655	3835
S. dilatata	2361	-	-	-	-
S. multicaulis	4330	5212	5390	-	-
S. nervosa	2015	-	-	-	-
S. racemosa	3568	3919	4026	4025	4169

4.2.10 Potential suitable area covered by protected areas in future

In both RCPs, suitable habitat for *Swertia* species is predicted to decrease in the future climatic scenarios (Appendices 23-29). Only four out of the seven species are expected to have potential suitability in the future. In RCP 6 based future climatic scenario, models predicted increased suitable area covered by PAs for all four species. *S. racemosa* had the largest area covered by PAs of 28203.88 km^2 which is 55.15% of the total suitable habitat predicted in 2050. The expansion in the suitable area is mostly seen in protected areas from central to eastern regions, especially in Annapuna CA, Kanchanjunga NP, Makalu-Barun NP and Sagamatha NP (Appendix 29). Although overall suitability has grown in 2070, the suitable area covered by PAs has fallen somewhat to 53.24%, indicating that suitable regions within the PAs have contracted.

Drastic change is seen in the case of *S. multicaulis* where the current suitability covered by PAs decreased to 96.02 km^2 from 151.22 km^2 in 2050. And in 2070, the potential suitable area covers only 33.15% of the total expected suitable area. Despite the fact that suitable habitat of *S. multicaulis* would be reduced in all PAs by 2050, Api-Nampa CA and Shey-Phoksundo NP showed suitability of 31.07 km^2 and 19.32 km^2 (Appendix 27) which was not observed under current climate. A similar trend is also seen in the case of *S. ciliata*. More suitable areas have expanded in the western region, and PAs from the west cover more suitable areas.

In RCP 8.5, suitability covered by PAs has increased for all except *S. multicaulis*. No suitable habitat was detected in either of the time periods for *S. multicaulis* in RCP 8.5. Similar to RCP 6, the suitability covered by PAs consistently decreased from 2050 to 2070.

4.2.11 Potential suitable area in Kalapani-Limpiyadhura Territory

Despite of the ongoing dispute over the Kalapani-Limpiyadhura territory with India, Nepal published a new political map adding those areas. Our models, predicted potential suitable area in the newly added Kalapani-Limpiyadhura territory for all species in current and for some species in the future climate scenarios (Table 7).

Under the current climate, the habitat suitability is seen for all seven *Swertia* species in Kalapani-Limpiyadhura but in the future climate, suitability is lost for three species; *S. angustifolia, S. dilatata* and *S. nervosa*. However, for the four remaining species, the predicted climate in Kalapani-Limpiyadhura region indicated a suitable environment. The most suitability is seen for *S. racemosa* with 208.16 km^2 of suitable habitat which expanded in both future time periods. Under the current climate, *S. multicaulis* has the smallest suitable area, measuring only 0.76 km^2. However, it increased to 54.05 km^2 in 2050 and dropped to 46.64 km^2 in 2070. However, no suitability is found in RCP 8.5.

Table 7: Potential suitable area in Kalapani-Limpiyadhura territory under current and future climate (2050 and 2070 in both RCP 6 and RCP 8.5)

***Swertia* Species**	**Suitable area (km^2) under current climate**	**RCP 6**		**RCP 8.5**	
		Suitable area (km^2) in 2050	**Suitable area (km^2) in 2070**	**Suitable area (km^2) in 2050**	**Suitable area (km^2) in 2070**
S. alata	9.06	10.38	5.19	8.89	0.74
S. angustifolia	2.29	-	-	-	-
S. ciliata	46.79	148.14	135.55	134.07	82.98
S. dilatata	3.04	-	-	-	-
S. multicaulis	0.76	54.05	46.64	-	-
S. nervosa	2.27	-	-	-	-
S. racemosa	208.16	273.43	289.73	278.62	303.07

4.3 Ecological Study

4.3.1 Habitat characteristics

The major biophysical variables recorded at the study sites are presented in Table 8. The topographic variables associated with the distribution of *S. multicaulis,* are more or less consistent across all population sites. The elevational range of the studied populations was 4591.8 masl to 4683.3 masl on average, making the HA$_2$ population near Dudhkunda the highest elevation site in the study area. The overall average slope was found to be 39.24°, showing the preference of *S. multicaulis* on the steep slopes. In terms of aspect, the north-east direction (12.5 ° to 41.9 °) was found to be the best for *S. multicaulis.* HA$_1$ and HA$_2$ sites had high rock cover (more than 10% cover) and the vascular plant cover was least in HA$_1$ (63.34%). The bare ground cover was found more in LA$_1$ site which is 4.11%. Soil chemical analysis of four different populations, showed a slightly acidic nature of the soil. The soil pH ranged from 6.4 to 6.6 (overall mean 6.58 ± 0.05) and the soil organic carbon content (%) varied from 0.82 (LA$_1$) to 1.65 (HA$_1$) with the overall mean of 1.30 ± 0.04.

Table 8: Biophysical variables (mean ± SE) characterizing *Swertia multicaulis* population

Biophysical parameters	**Sampling sites**				**Overall mean**	**p-value**
	LA$_1$	**LA$_2$**	**HA$_1$**	**HA$_2$**		
Slope (°)	48.08 ± 4.59^{a}	45.96 ± 3.98^{a}	36.78 ± 3.8^{a}	26.14 ± 5.75^{b}	39.24±5.01	0.02
Aspect (°)	41.9±3.13	12.5±1.25	16.6±1.41	37.20±3.31	27.05±1.52	-
pH	6.63±0.03	6.6±0.04	6.44±0.07	6.64±0.03	6.58±0.05	-
Elevation (masl)	4546-4690	4644-4676	4640-4722	4670-4688	4651.58 ± 20.63	-
RRI	-0.07±0.1	0.23±0.08	-0.12±0.08	0.41±0.08	0.11±0.04	-
***S. multicaulis* cover (%)**	4.58 ± 0.33^{ab}	6.2 ± 0.48^{b}	3.54 ± 0.33^{a}	4.39 ± 0.4^{a}	4.68±0.56	< 0.001
Vascular plant cover (%)	75.31±3.1	77.83±1.75	63.34±5.18	71.61±1.83	72.02±3.16	-
Rock cover (%)	7.03 ± 1.9^{a}	6.12 ± 1.22^{a}	20.38 ± 4.54^{b}	11.98 ± 1.87^{ab}	11.38±3.27	0.01
Lichen cover (%)	2.6 ± 0.47^{ab}	1.4 ± 0.19^{b}	2.03 ± 0.33^{a}	3.81 ± 0.28^{a}	2.46±0.51	< 0.001
Bryophyte cover (%)	4.53±0.56	4.48±0.64	9.15±1.78	4.8±0.32	5.74±1.14	-
Bare ground Cover (%)	4.11±0.83	1.63±0.33	1.58±0.29	1.56±0.24	2.22±0.63	-
Litter cover (%)	1.84 ± 0.2^{a}	2.34 ± 0.4^{a}	0.4 ± 0.22^{b}	1.85 ± 0.18^{a}	1.61±0.42	< 0.001

SOC (%)	0.82±0.04^{a}	1.27±0.04^{a}	1.65±0.05^{b}	1.44±0.13^{a}	1.3±0.04	< 0.001
Distance from nearest trail (km)	0.66±0.01^{a}	0.93±0.01^{a}	0.48±0.02^{b}	1.02±0.01^{c}	0.77±0.02	< 0.001
Distance from nearest settlement (km)	0.66±0.01^{a}	1.59±0.01^{a}	1.69±0.02^{b}	2.07±0.01^{c}	1.5±0.04	< 0.001

Note: The different superscript letters in a row represent that the medians are significantly different from one another at $p < 0.05$ based multiple comparisons on Kruskal-Wallis test.

4.3.2 Variation in population density of *Swertia multicaulis* and relationship with environmental variables

The population density of *S. multicaulis* was calculated in terms of number of individual plants at different life stages per sub-plot (1m×1m) in each population (Table 9). The total plant density varied from 9.84 plants per m^2 in higher elevation population HA$_1$ to 11.72 plants per m^2 in lower elevation population LA$_1$ with overall mean density of 11.33 plants per m^2. In another high elevation population HA$_2$, the young plant density was found to be the lowest (1.84 plants per m^2) but juvenile-1 density was highest (4.02 plants m^{-2}) compared to the rest of populations. In all populations, the adult reproductive density appears to be rather consistent.

Table 9: Density (plants per m^2) of *Swertia multicaulis* in different population and in different life stages

Different Populations	**Young Plant Density**	**Juvenile-1 Density**	**Juvenile-2 Density**	**Juvenile-3 Density**	**Adult Vegetative Density**	**Adult Reproductive Density**	**Overall Density**
LA$_1$	4.5±0.44	2.4±0.32	1.22±0.16	0.32±0.08	0.64±0.13	2.64±0.33	**11.72±0.87**
LA$_2$	4.04±0.46	3.66±0.31	2.06±0.21	0.66±0.12	0.51±0.12	2.48±0.22	**13.4±0.63**
HA$_1$	2.72±0.4	2.72±0.3	1.46±0.19	0.2±0.06	0.54±0.09	2.26±0.28	**9.84±0.72**
HA$_2$	1.84±0.26	4.02±0.34	1.42±0.21	0.34±0.1	0.28±0.08	2.44±0.24	**10.34±0.5**
Total	**3.28±0.21**	**3.2±0.17**	**1.54±0.1**	**0.38±0.05**	**0.49±0.05**	**2.46±0.14**	**11.33±0.36**

The effect of various environmental factors on *S. multicaulis* density across different life-stages was examined using a generalized linear mixed model (GLMM). Prior to the analysis, highly correlated variables were eliminated, and only nine variables were retained. GLMM revealed two to four variables that have significant relationship with the density of *S. multicaulis* at different life-stages (Table 10). Among these variables, distance from the nearest trail showed a positive significant relationship with juvenile (Figure 6c), adult reproductive (Figure 7a) and total plant density (Figure 7c) of *S. multicaulis*. In the case of young plant density, non-vascular cover showed a positive relationship. Elevation had a negative influence on young (Figure 6b) and adult reproductive density (Figure 6f). But litter cover showed negative relationship with adult reproductive (Figure 6e) and total plant density (Figure 7c). No significant relationship between environmental variables and the adult vegetative plant density was detected.

Table 10: Effects of variables on the density (plants per m^2) of *Swertia multicaulis* based on generalized linear mixed models

Density Category	**Important Variables**	**Estimate**	**Standard Error**	**AIC**
Young plant density	Intercept	1.049***	0.09	Null = 972.81 Full = 961.08
	Elevation	-0.286**	0.087	
	Non-vascular plant cover	0.109*	0.053	
Juvenile plant density	Intercept	1.584***	0.049	Null = 1024.18 Full = 1008.53
	Bare ground	-0.13**	0.044	
	Distance from the nearest trail	0.15**	0.05	
Adult reproductive plant density	Intercept	0.834***	0.068	Null = 773.82 Full = 772.27
	Elevation	-0.23*	0.091	
	Litter cover	-0.124*	0.063	
	Distance from the nearest trail	0.207*	0.082	
Total plant density	Intercept	2.403***	0.039	Null = 1236.99 Full = 1234.43
	Litter cover	-0.061*	0.028	
	Distance from nearest Trail	0.092*	0.042	

Note**:** Parameters were estimated assuming a Poisson distribution for density. A random effect of “plot” was included for density as a random factor in the models. Levels of significance are indicated by the symbols; $p < 0.001$ ‘***’, $p < 0.01$ ‘**’, $p < 0.05$ ‘*’.

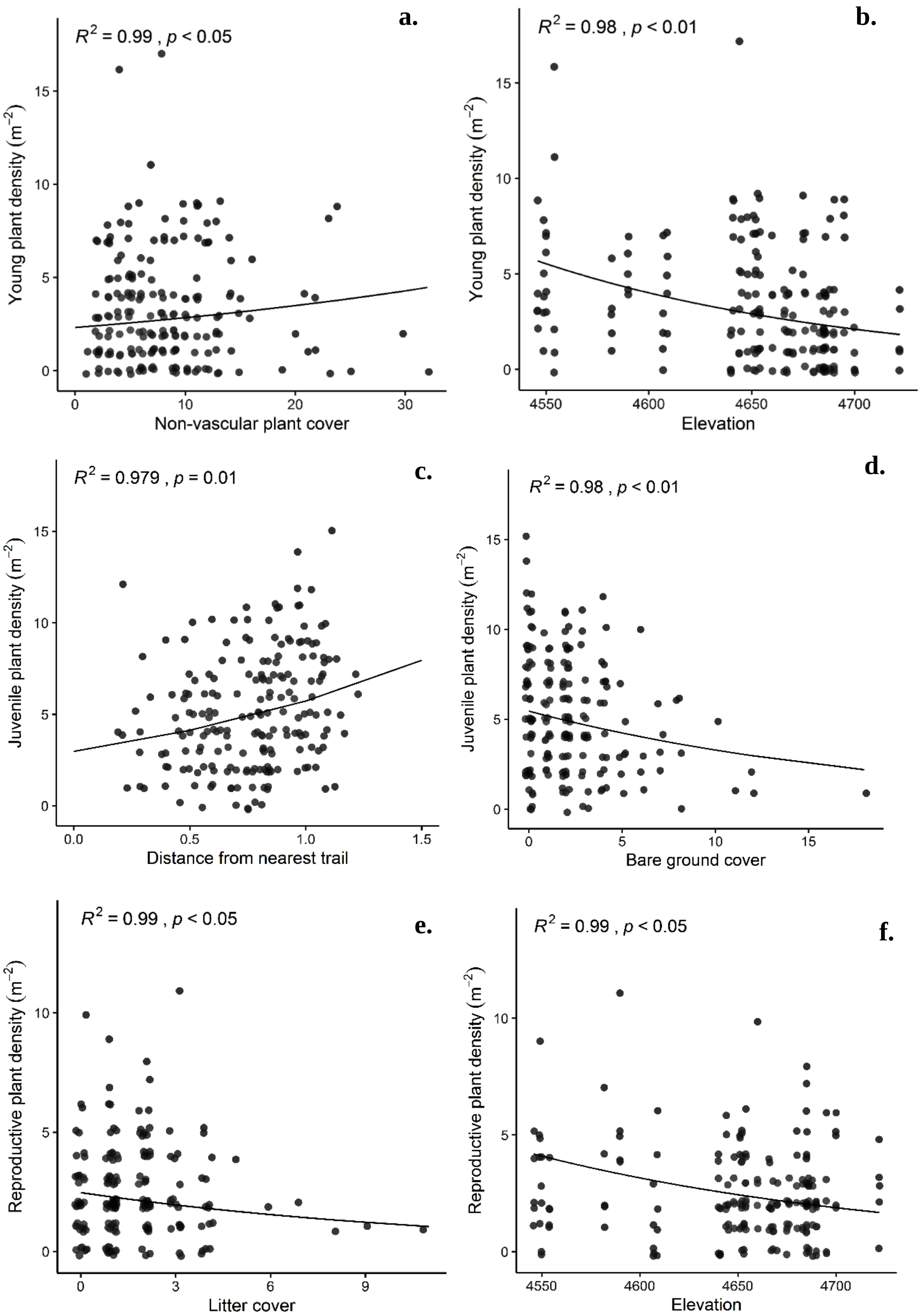

Figure 6: Effect of **a.** non-vascular plant cover and **b.** elevation on young plant density; **c.** distance from nearest trail and **d.** bare ground cover on juvenile plant density; **e.** litter over and **f.** elevation on reproductive plant density based generalized linear mixed model.

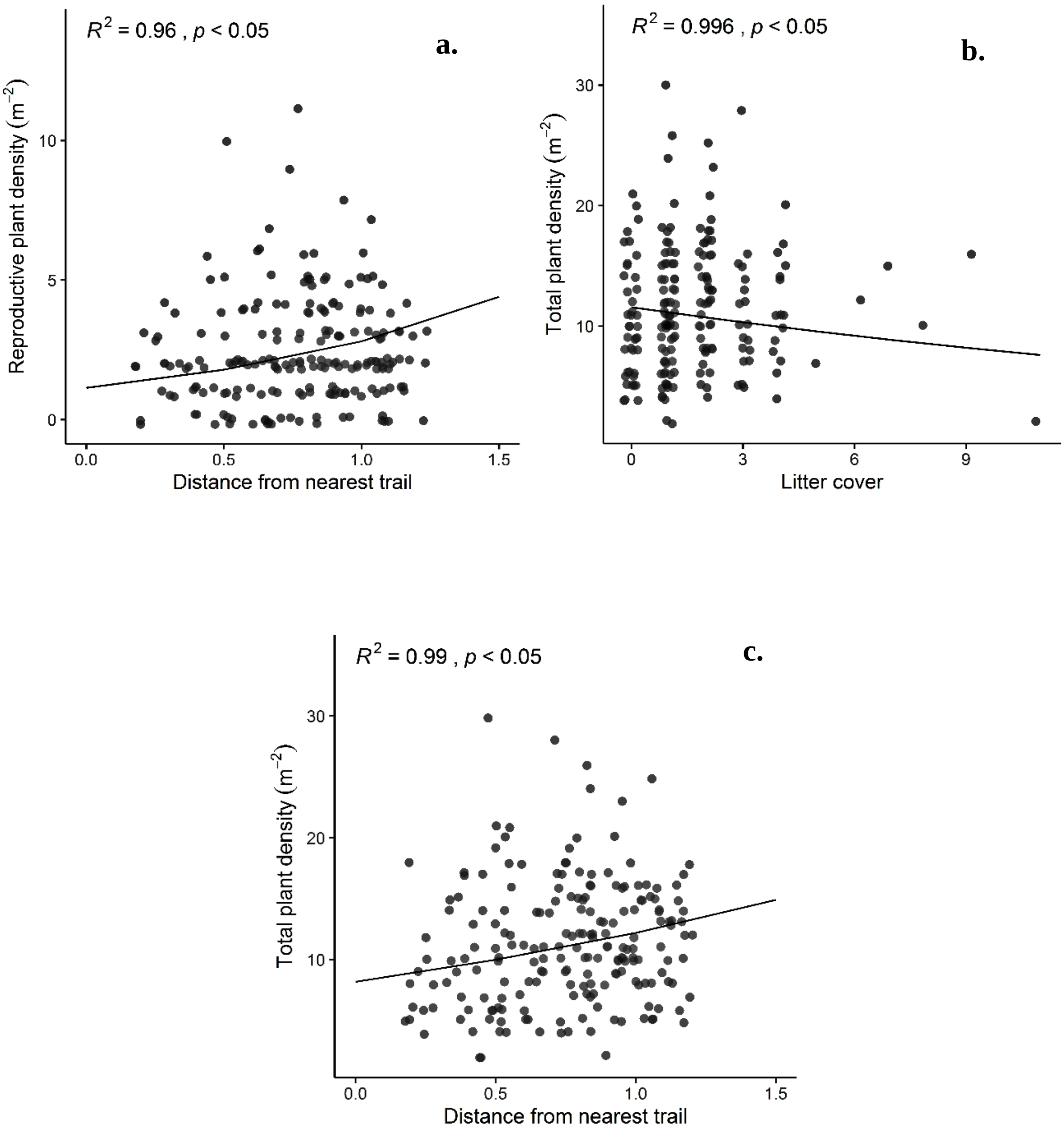

Figure 7: Effect of **a.** distance from nearest trail on reproductive plant density**; b.** litter cover and **c.** distance from nearest trail on total plant density based generalized linear mixed model.

4.3.3 Variation in population structure *Swertia multicaulis* and regeneration potential

A relatively high proportion of juvenile plants (0.45 in total) was found for *S. multicaulis* in LNP (Figure 8). The overall proportions of young plant, juvenile-1, juvenile-2, juvenile-3, adult vegetative and adult reproductive were 0.29, 0.28, 0.14, 0.03, 0.04 and 0.22 respectively (Figure 7). The lowest proportion of young (0.18) was found in the higher elevation, HA_2 population and the lowest juvenile-1 (0.2) proportion was for lower elevation LA_1 population. But the proportion of adult reproductive was found to be relatively higher in the HA_2 population.

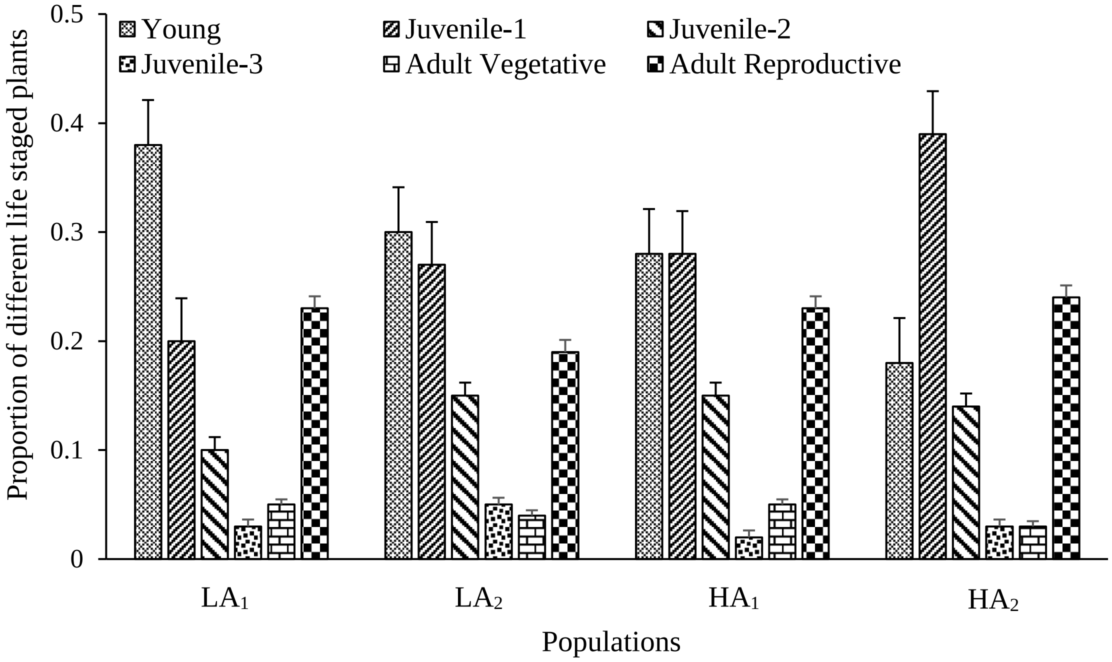

Figure 8: Proportion of different life-staged *Swertia multicaulis* in different populations

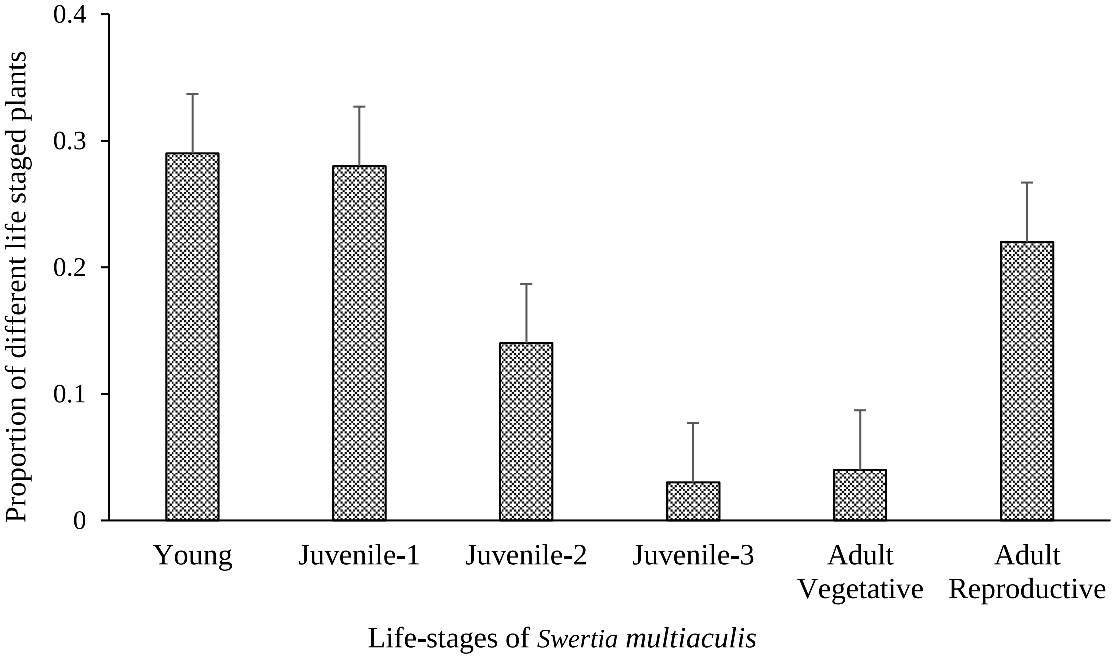

Figure 9: Proportion of different life-staged *Swertia multicaulis*

The regeneration potential was calculated as a ratio of density of young plants to density of remaining plant individuals other than young. The maximum regeneration potential was found in the LA_1 population, which is 0.62 and the lowest in HA_2 which is 0.22 (Figure 9) indicating comparatively weak regeneration performance of *S. multicaulis* in HA_2.

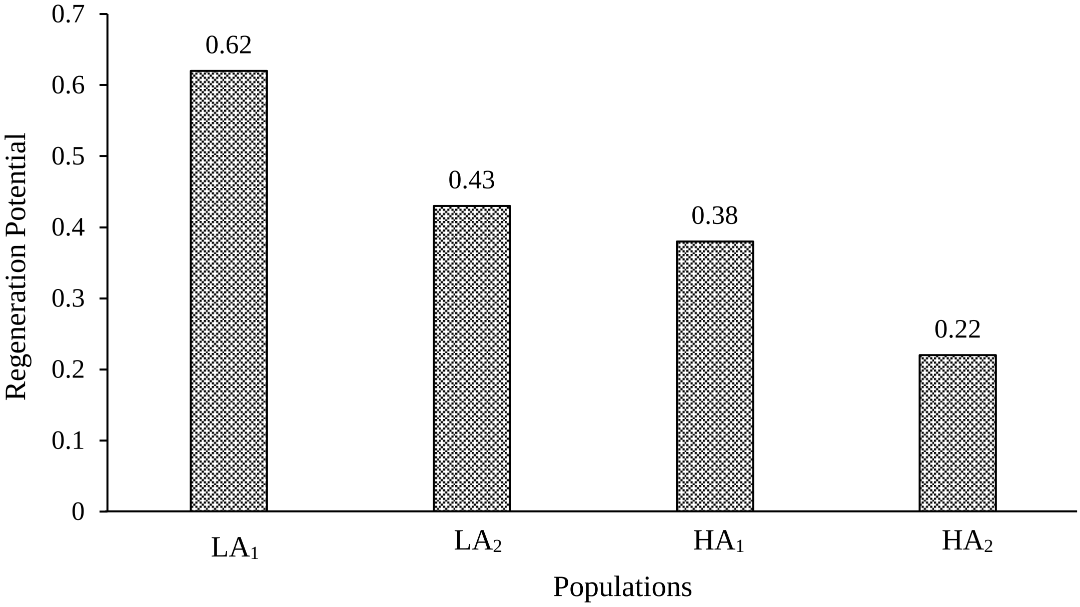

Figure 10: Regeneration potential of *Swertia multicaulis* in different population

4.2.4 Vegetative and reproductive traits of *Swertia multicaulis*

Variations in plant performance-related traits (sexual and vegetative traits) of *S. multicaulis* were studied in all populations. Out of 16 traits, 5 traits related to above ground vegetative growth, 2 traits related to below ground and 9 related to reproductive performance were studied. The mean values of vegetative and reproductive traits are presented in Table 11. The traits considered, include leaf number, rosette diameter, length and breadth of largest leaf, number of buds and flowers, number of fruits, inflorescence length, flower diameter and fruit volume.

The overall mean value of the number of leaves and rosette diameter was found to be 15±0.29 and 8.54±0.36 cm respectively, which is more or less similar in all populations. But, the length and breadth of the largest leaf were smallest in the LA_1 population and the highest were recorded in LA_2 population. LDMC was found high in the lower elevation sites, LA_2 and LA_1. No flowers or buds were seen in the LA_1 population, but average of 32±4.46 number of fruits were recorded. The reproductive traits (inflorescence length, fruit length and diameter) were higher in the LA_2 population than the others. Although the number of flowers and buds was found high in the HA$_1$ population, the rest of the reproductive characteristics (inflorescence length, number of fruits and fruit length) were low compared to other populations. The average root length was found to be 24.09±1.21 cm with an average root thickness of 8.06±0.32 cm. Root was found longest (28.27±2 cm) in HA$_1$, but the root thickness or diameter was the smallest (7.71±0.52 cm) across all the populations.

Table 11: Vegetative and reproductive traits of *Swertia multicaulis* at different life stages

Plant traits	**Sampling sites**				**Overall mean**	**p-value**
	LA$_1$	**LA$_2$**	**HA$_1$**	**HA$_2$**		
Leaf number per plant	14±0.64	14±0.52	15±0.83	15±0.5	15±0.29	-
Rosette diameter (cm)	8.22±0.37^{a}	9.6±0.26^{b}	7.96±0.14^{a}	8.39±0.29^{a}	8.54±0.36	< 0.001
Leaf length (cm)	3.84±0.21^{a}	4.86±0.15^{b}	4.04±0.1^{a}	4.13±0.17^{a}	4.22±0.22	< 0.001
Leaf breadth (cm)	0.59±0.01^{ab}	0.62±0.01^{ab}	0.58±0.01^{a}	0.66±0.02^{b}	0.61±0.02	0.03
Leaf dry matter content (gg-^{1})	0.13±0.01^{a}	0.15±0.01^{a}	0.1±0.01^{b}	0.08±0.04^{a}	0.12±0.01	< 0.001
Number of buds	-	0.2±0.17	0.16±0.1	0.1±0.1	0.12±0.04	-
Number of flowers	-	0.75±0.43	0.98±0.42	0.38±0.16	0.53±0.21	-
Number of fruits	32±4.46^{ab}	41±2.68^{b}	23±2.53^{a}	32±2.97^{b}	32±3.67	< 0.001
Inflorescence length (cm)	6.4±0.76^{a}	9.44±0.55^{b}	4.71±0.4^{c}	6.34±0.52^{b}	6.72±0.99	< 0.001
Flower diameter (cm)	0.2±0.02^{a}	0.22±0.13^{a}	0.27±0.08^{b}	0.18±0.08^{a}	0.17±0.05	0.04
Fruit length (cm)	0.95±0.1	1.09±0.03	0.88±0.07	0.99±0.06	0.98±0.04	-
Fruit diameter (cm)	0.3±0.036	0.31±0.006	0.34±0.033	0.34±0.025	0.32±0.01	-
Fruit volume (cm^{3})	0.11±0.01	0.1±0.01	0.14±0.02	0.13±0.01	0.12±0.01	-
Root length (cm)	21.96±3.24	24.92±1.97	28.27±2	21.2±1.88	24.09±1.21	-
Root thickness (cm)	7.83±0.38	8.7±0.5	7.71±0.52	8.81±0.63	8.06±0.32	-

Note: The different superscript letters in a row represent that the medians are significantly different from one another at $p < 0.05$ based multiple comparisons on Kruskal-Wallis test.

4.2.5 Allocation pattern in *Swertia multicaulis*

The biomass of *S. multicaulis* was more concentrated in underground parts (about 41% of the biomass was centered in the root) than that of above ground parts. In all the four populations studied, below ground allocation was found to be much higher than the above ground asexual and sexual allocation. All the populations differ significantly in terms of allocation pattern (Table 12). The total mean allocation (2.83 gm ±0.48) and the allocation for different components were highest for the LA_2 population and the lowest was found in the HA_1 population.

Table 12: Variation in biomass allocation of *Swertia multicaulis*: mean plant dry weight (gm) across all populations of sexual allocation, asexual above ground allocation, below ground allocation and total allocation

Biomass Components	**Populations**				**Overall Mean**
	LA_1	**LA_2**	**HA_1**	**HA_2**	
Sexual allocation	$0.74±0.09^a$	$1.01±0.13^a$	$0.2±0.03^b$	$0.94±0.13^a$	0.72±0.07
Asexual above ground allocation	$0.28±0.02^a$	$0.36±0.06^a$	$0.18±0.07^b$	$0.32±0.06^a$	0.28±0.03
Below ground allocation	$1.26±0.19^a$	$1.46±0.2^a$	$1.22±0.12^a$	$1.28±0.24^a$	1.31±0.09
Total allocation	$2.27±0.22^a$	$2.83±0.28^a$	$1.6±0.18^b$	$2.54±0.34^a$	2.31±0.15

The different superscript letters in a row represent that the medians are significantly different from one another at $p < 0.05$ based multiple comparisons on Kruskal-Wallis test.

4.2.6 Reproductive and vegetative effort of *Swertia multicaulis*

Reproductive effort (RE) or vegetative effort (VE) is calculated as the ratio of a particular biomass to the total biomass of the plant. The studied populations significantly differed in terms of reproductive and below ground vegetative effort. All populations had the lowest reproductive and above-ground vegetative efforts. The reproductive effort (ratio of inflorescence biomass to total biomass) was highest for LA_1 population (Figure 11) and the below ground vegetative effort was highest in the HA_1 population.

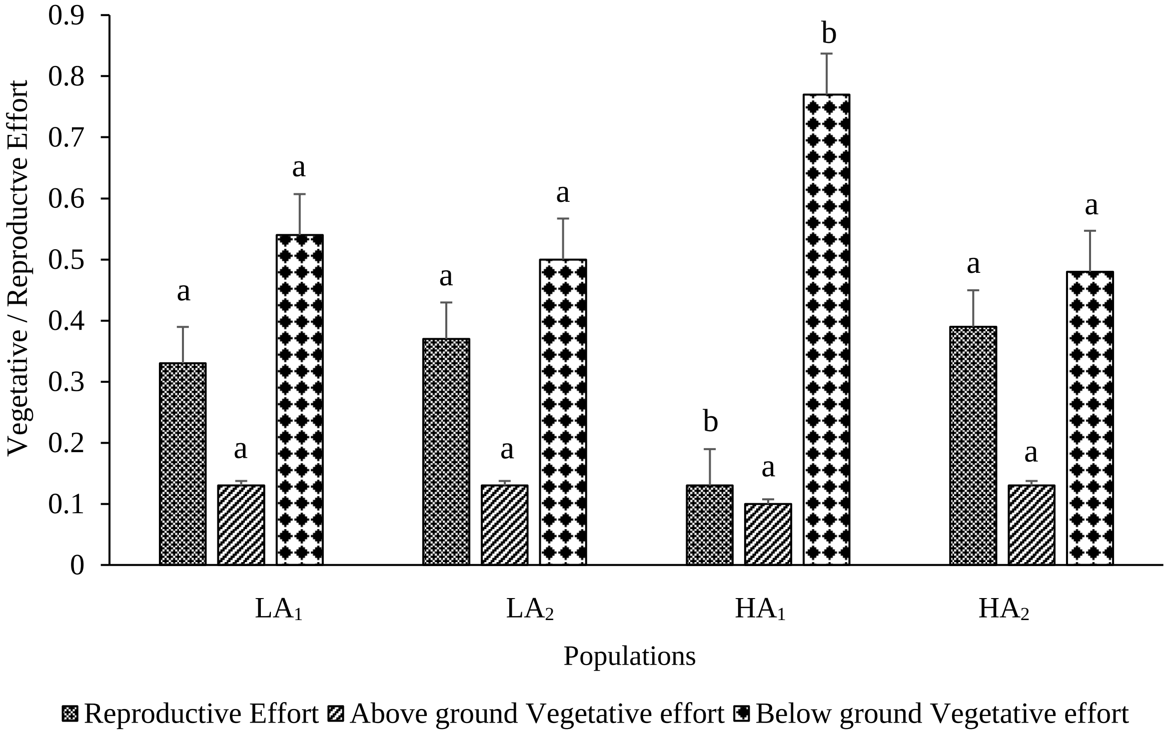

Figure 11: Variation in reproductive and vegetative effort among different populations of *Swertia multicaulis*. Bars with different letters represent significant difference at $p < 0.05$ in reproductive/vegetative effort among populations based multiple comparisons on Kruskal-Wallis test.

CHAPTER V: DISCUSSION

5.1 Morphology and Distribution of *Swertia*

The current study focused on the seven species of genus *Swertia* out of 29 found in Nepal (Shrestha *et al.*, 2022) which are either traded directly or as an alternative to *S. chirayita* (Barakoti *et al.* 2002, Pyakurel *et al.*, 2019). The genus is widespread throughout Nepal from the eastern to western regions though some species (like, *S. multicaulis*) are limited to only one region or any two of them. Most of the species are reported from the central region. They also have a broad range of vertical distribution, ranging from a sub-topical zone of 340 m (*S. angustifolia*) to alpine meadows of 5115 m (*S. multicaulis*). Most of the species were reported from sub-tropical to sub-alpine zone of Nepal. Our study revealed a similar distribution of *Swertia* species in Nepal, as noted in earlier studies by Joshi and Dhawan (2005), Rijal (2009), and Khanal *et al.* (2014).

Morphologically, some of these species have very similar features, making it challenging to distinguish between them and creating issues in the taxonomy of these species. Many species present in Nepal are also being described as a synonymous with each other. For example, *S. dilatata* has been treated as *S. paniculata; S. pedicellata* as *S. ciliata* and *S. racemosa* as *S. teres* in the Flora of Bhutan (Rijal, 2009). Same species has been treated differently or merged with similar looking species within Nepal in different published literatures. For example; *S. dilatata* and *S. paniculata* were both treated separately in Press *et al.* (2000) but in Rajbhandari *et al.* (2015 & 2017) *S. paniculata* is merged within *S. dilatata.* But again, in Shrestha *et al.* (2022) both are treated differently. So, the primary characteristics like; the plant's inflorescence characteristics, such as presence or absence of cilia, presence or absence of a purple band on the petals, number and color of petals, number of glands, number of stamens and other morphological features were considered to identify these species in the current study as done by Rijal and Joshi (2007), Joshi and Joshi (2008) and Nampy *et al.* (2015). The present study followed the most recent literature by Shrestha *et al.* (2022) and treated the species as it is.

5.2 Species Distribution Models

SDMs have become a common tool used by conservation practitioners for understanding the environmental conditions inhabited by species and predicting the distribution (Fourcade *et al.*, 2014; Phillips *et al.*, 2017). These methods are being used as a valuable and cost-effective tool for understanding species occurrence probability with given environmental data in identifying sites for reintroductions, forecast consequences of environmental change, predicting the extent of species invasions, addressing the ecological and evolutionary questions (Peterson, 2006; Araujo *et al.*, 2019). In addition, such models are of great value in targeting field surveys for the discovery of new unknown populations (Fois *et al.*, 2015).

SDMs can perform well in characterizing the distributions of species, can provide useful ecological insight. Hence, the use of SDMs has increased rapidly in recent years with the development of several new modelling techniques (Phillips *et al.*, 2006; Araujo *et al.*, 2019). There are several algorithms available for constructing distribution models, and have been compared widely (Zhu & Peterson, 2017; Hao *et al.*, 2021), yet no single algorithm is considered the best for modeling purpose (França & Cabral, 2015; Qiao *et al.*, 2015). Ensemble modelling is another technique that has recently gained popularity in the research of how climate change may affect species' potential spatial distribution. Ensemble models combine the outputs of multiple modeling techniques. However, the problem with the ensemble modelling is, the output of algorithms with more accuracy and less accuracy both get averaged and the final result is predicted which suggest that these approaches will produce less than optimal results (Qiao *et al.*, 2015; Zhu & Peterson, 2019). We have chosen Maxent because of its high performance (Elith *et al.*, 2010) and common use in biogeography (Joppa *et al.* 2013). It has the capacity to model complex relationships and interactions with excellent predictive ability and even with the small sample size of 10-30 occurrences (Wisz *et al.*, 2008; Phillips & Dudik, 2008; Qiao *et al.*, 2015) and typically outperforms other methods based on predictive accuracy (Merow *et al.*, 2013). Maxent thus offers excellent potential for extracting useful biogeographical information from small samples of locality records than the others (Pearson, 2007) and is considered one of the most efficient approaches in SDM using presence only data (Elith *et al.*, 2011).

Although the modeling process is robust, there are some limitations in predicting the impacts of climate change. These limitations mainly arise due to uncertainties of future greenhouse gas emissions (Ranjitkar *et al.*, 2014; Zomer *et al.*, 2014). SDMs only indicate potential suitable habitats where the species may be found but does not guarantee their actual occurrence (Peterson *et al.*, 2011), adding a degree of uncertainty to the modelling process (Elith *et al.*, 2006; Peterson *et al.*, 2006 & 2011). Several factors influence a species' ability to adapt and survive in novel climates, including seed dispersal range, habitat distance, biotic and abiotic resistance, and physiological adaptability (Corlett & Westcotta, 2013). These models could be very useful before making any conservation policies, planning of cultivation, relocation of threatened plants or to find suitable harvesting locations, and establish sustainable conservation strategies.

5.3 Performance of SDMs

The performance of all models was evaluated on the basis of threshold independent AUC based on geographic cross validation. All the models were predicted after filtering the data by environmental thinning of the occurrences. The findings indicated that all species had better-than-random predictions (AUC > 0.5). The lowest AUC value 0.63 was for *S.* which is lower compared with the prediction of the rest of the species but still better than random prediction. Addition of more presence records from different localities would have resulted higher AUC value resulting a better prediction (Weiz *et al.*, 2008) as AUC value increases with more occurrences within the same study area for the same species.

Narrowing the geographic range of pseudo-absences to a very small area or selecting them from an excessively large area can lower the model accuracy (Fourcade, 2014). For all the models, 10,000 pseudo-absences were randomly generated in the entire area of the country. However, by understanding the distribution range of species and limiting the background to an extent where species might possibly occur would have given a better prediction with more accurate AUC (Smith, 2013). For example, in the case of *S. multicaulis* which is an alpine plant, excluding the lower Tarai region or the region below 2000 m elevation would certainly result better prediction as there is no way that the plant would shift to lower elevation.

5.4 Current Potential Suitability and Contribution of Variables

Our models strongly predicted the hilly region to be suitable for most of the species. For *S. multicaulis*, sub-alpine to alpine regions is more suitable. The field surveys and published studies (Rijal, 2009; Joshi & Joshi, 2008) have shown similar distribution range of the species. *S. multicailis* which is recorded mostly from Bagmati province towards eastern regions only (Rijal, 2009; Joshi & Joshi 2008; Shrestha *et al.*, 2010), is also predicted to have suitability in alpine areas of Gandaki province, which implies there is a huge possibility to find this species there. SDMs thus helps in identifying those new potentially suitable areas which should be explored and prioritized for cultivation or conservation. However, caution is essential, as there are other important factors, determining the actual distribution. Hence, further investigations of microclimatic conditions, abiotic/biotic interactions or dispersal limitations are also needed.

When assessing a species' suitability, each variable has a specific relevance. Global horizontal irradiance and annual mean temperature were the most often repeated variables among those selected variables for each species. For all of the species, probability of occurrence decreased with increase in global horizontal irradiance. This could be because of the adverse effects of increasing solar irradiance which might cause assimilatory reduction and UV damage to the photosynthetic system (Kataria *et al.*, 2014; Paudeyal *et al.*, 2021). All the species studied here has medicinal values. Human influence is clearly seen in the cases of *S. alata, S. angustifolia,* and *S. dilatata,* with more than 10% variable contribution in each species, posing a conservation issue. But for *S. multicaulis,* human impact is comparatively less than others. Since, it is an alpine species, and its habitat is not easily accessible in comparison to the rest of the species.

Temperature and precipitation play a crucial role in defining a plant's ecological niche (Salick, 2014) and are vital for species occurrence (Pearson & Dawson, 2003). The combination of rainfall and temperature, along with other factors, during the peak growing season has a significant impact on the growth of leaves and stems (Larcher, 2012). For *S. multicaulis,* the driest month's precipitation and annual mean temperature were found to be important variables in defining the appropriate habitat in the alpines. Since the alpine areas are characterized by low temperatures, unstable substrates and short growing seasons (Körner, 2003; Wang *et al.*, 2017; Applequist *et al.*, 2020), precipitation of the driest month with more than 10 mm rainfall and mean annual temperature ≈ -5 °C were ideal for the seed germination and overall growth for *S. multicaulis.* The suitability of *S. racemosa* was found throughout the country in current and future climate scenarios. Along with the mean annual temperature, the driest month's precipitation and the coldest quarter's precipitation were key factors in suitability. About 75.59% contribution is from precipitation related variables. Both precipitation of the driest month and coldest quarter had played significant role in identifying suitable areas. To have suitability in western to eastern regions the precipitation of the coldest quarter could have played significant role. During the monsoon, more rainfall is in the eastern part but in the winter, western part of the country receives more rainfall (DHM, 2017). Therefore, *S. racemosa* may get benefited from the precipitation from the western area during the winter or from the eastern region during the summer monsoon.

5.5 Future Potential Suitability

Our models for the future climate under both emission scenarios predicted a significant reduction in suitable areas for all studied species except for *S. racemosa*. For *S. angustifolia*. *S. dilata* and *S. nervosa* suitability decreased to minimum in 2050 and 2070. In contrast, for *S. racemosa* the future climate seems to be favorable as the suitable area is increasing in both emissions in both time periods but towards the higher elevation.

Our analysis also suggests that in future climate scenarios, suitable habitats for the species will shift to higher elevations in northern regions. However, this increased suitability at higher elevations could lead to a "summit trap" phenomenon, causing the plant population to decline and potentially face extinction (Salick *et al.*, 2009). There could be a lot of possibilities that the species may not survive in future with the changing climate in higher elevation. The effect of climate change appears to be more severe in high mountains (Shrestha *et al.*, 2012; Salick *et al.*, 2014). The survival of species in alpine environments appears to be increasingly difficult in the future. This raises the questions about the future survivability of plants like *S. mulicaulis* or *S. nervosa* which are currently present in alpine or sub-alpine environments. Besides that, suitability of a species in a new region or at a higher elevation does not imply its presence (Peterson *et al.*, 2011). It depends on number of factors to adapt and survive in new environments, including plants physiological flexibility, habitat distance, biotic interactions, and seed dispersion range (Bahn *et al.*, 2012) which adds uncertainty to the predictions (Elith *et al.*, 2006; Pearson *et al.*, 2006; Peterson *et al.*, 2011).

5.6 Suitability in Protected Areas

In future climate scenarios, the overall expected suitability of all species (except for *S. racemosa*) is declining. However, the percentage cover of predicted suitable area by PAs seems to have increased in respective time period than the outside of PAs in both future climatic scenarios. In the case of *S. multicaulis,* which is the only alpine species of *Swertia* under the study, nearly 78% of total predicted suitable area was within PAs under the current climate which in 2050 in RCP 6 reduced to 30.3% of suitable area predicted in that time period. However, for the remaining species, lost in the suitable habitat is predicted more outside of PAs than inside in the respective future time periods which demonstrates the importance of PAs in conservation of the species in the future. But this raises the question of whether PAs are capable of preserving plant species with very limited distribution which is expected to decline in future or not. Such species in these regions need more conservation attention than any other. Such plant species should be prioritized for conservation in PAs. It also becomes necessary to consider suitable environment and its possible shifting in the future before making any plans or polices or establishing any protected for appropriate conservation of such species. But majority of conservation efforts are concentrated on protecting the flagship animal species (Bhattrai & Ghimire, 2006) and plant species are usually underrepresented (Shrestha *et al.* 2010).

5.7 Habitat Characteristics and Variation in Population Density and Structure of *Swertia multicaulis*

The study is based on the four different populations around the Gosainkunda in Lamtang NP. All of the studied populations were distinguished by open alpine meadows in north-east facing slopes with slightly acidic soil. In all populations, *S. multicaulis* was recorded in open steep with overall mean density of *S. multicaulis* 11.33 plants per m^2. The population from the high elevation HA_2 site had a higher proportion of juveniles and adult plants, with a poor representation of young plants, reflecting the condition of lower regeneration potential compared to the other populations. On the other hand, the proportions of young plants and adult reproductive were higher in the LA_1 population, which is at a lower elevation with the highest regeneration potential. The reduced cold with slightly longer growing period in the lower elevation (Körner, 2003; Wang *et al.*, 2017) and less rock cover may have positively influenced the density of the LA_1 population. Most of the vegetative and the reproductive traits measured were found least in the higher elevation site HA_1 which could be the result of harsh in the microclimatic conditions (Bresson *et al.*, 2011). Besides that, HA_1 was much closer to the nearest trail which makes it an easier site for possible disturbances. In addition to that, HA_1 was much rockier (20.38% of 1 m^2) compared to the rest of the sites.

Similar to the strategy of many alpine plants, like *Neopicrorhiza scrophulariiflora* (Poudeyal *et al.*, 2019) and *Aconitum spicatum* (Chapagain *et al.*, 2019) to allocate large amounts of resources to the growth of underground structures, *S. multicaulis* was also found to allocate most of its biomass in the root portion. Investing more of the resources in below ground parts is considered as an adaptive strategy of high elevation plants to produce annual aerial parts shortly after snow melt (Chapagain *et al.*, 2019). In all populations, *S. multicaulis* was found to allocate more than 40% of the total biomass to below ground parts. Even in the high elevation, HA_1 site where more percentage of rock cover was present with low vascular plant cover, the below ground vegetative effort was found to be the highest compared to the rest of the population. But, the higher sexual allocation and the asexual above ground allocation of *S. multicaulis* were found in the lower elevation LA_2 site. This could be the result of favorable environmental conditions at the lower elevation (Galloway, 1995) as plants have allocated more vegetative biomass.

5.8 Density of *Swertia multicaulis* and Environmental Variables

Different environmental factors directly affect the population and individual growth of the plant. Understanding the relationship between environmental factors, population structure and plant functional traits is essential for ensuring the sustainability of the plant population over long periods of time (Chapagain *et al.*, 2019). Generalized linear mixed models (GLMM) showed the combination of litter cover, distance from nearest trail and elevation as the principal components having greater influence on the population density of *S. multicaulis*. In the study area, we recorded *S. multicaulis* from the moist north-east facing slopes similar to *N. scrophulariiflora* (Shrestha & Jha, 2009; Paudeyal *et al.*, 2019). North facing slopes receives low light and precipitation but water from the melting snow makes the soil moist (Shrestha & Jha, 2009). However, GLMM did not identify slope and aspect related RRI as significant variable, which could be because of similar habitats across all populations. The non-vascular plant cover and elevation had a negative influence on young plant density. In alpine regions where resources are limited, the soil surface covered by non-vascular plants can inhibit the establishment and growth of young plants by limiting their access to nutrients and water. Besides that, non-vascular plants, particularly bryophytes, have been found to inhibit the germination of vascular plants (Soudzilovskaia *et al.*, 2010).

In juvenile, adult reproductive and total densities, distance from the nearest trail showed a positive relationship. The plant density increased with increasing distance from the trail, probably as a result of less human interference. The adult reproductive density of *S. multicaulis* exhibited a decreasing pattern with increasing elevation. This decrease in density could be the result of increased solar irradiance at higher elevations damaging the photosynthetic system, leading to reduced photosynthetic efficiency (Hollósy, 2002; Kataria *et al.*, 2014; Paudeyal *et al.*, 2021). Furthermore, plants in high elevations are subjected to high environmental stress, such as lower temperatures and shorter growing seasons, which hinders their growth potential (Wang *et al.*, 2017).

CHAPTER VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Species distribution modelling has provided a comprehensive analysis of the underlying environmental factors determining the ecological niche of traded *Swertia* species in Nepal. The study has also successfully predicted the hilly regions as suitable for five of the *Swerita* species excluding *S. multicaulis* and *S. racemosa* which are sub-alpine and alpine species, respectively. The most commonly repeated variables influencing the distribution were global horizontal irradiance and annual mean temperature. The study revealed a reduction in suitable areas for all studied species in future climate scenarios in both RCP pathways, except for *S. racemosa*. Additionally, the suitable habitat for all species is projected to shift towards higher elevations in the northern regions.

The study on the population ecology of *S. multicaulis* indicated that populations located at higher elevations (such as in HA_1 or HA_2) which are subjected to high environmental stress exhibited less pronounced vegetative and reproductive traits. The densities of young and adult reproductive plants decreased significantly with increasing elevation. The regeneration potential of the plant was also found low in the populations at higher elevation. Interestingly, the study revealed the allocation of below ground biomass to be highest in the high elevation site HA_1, which is rockier than the other populations. Furthermore, the study found that a greater distance from the nearest trail was beneficial for the *S. multicaulis* population as there is less human disturbance. Further studies are required outside of protected areas, as there is a greater risk of unsustainable harvesting, and a comparative study should be conducted to get a conclusive result about the ecological status of *S. multicaulis*.

Recommendation / Perspectives

Climate change and overexploitation are expected to have a severe impact on the physiology and ecology of medicinally important plants. It is important to maintain viable population of such medicinal plants through appropriate policies, guidelines and management strategies integrating ecological and biogeographical studies, local knowledge and practices and community requirements.

Harvesting of medicinally important species can be made sustainable by applying the best approach which ensures the long-term viability of harvested populations. This includes managing or controlling overharvesting, harvest of specific amount prescribed at specific period of time (e.g., at the end of growing season) applying tested harvest method. Another would be the biocultural conservation of such species (Salick *et al.*, 2014). And for the species whose climatic suitability is limited in future climate scenarios in a particular region, facilitated or assisted migration (Müller & Eriksson, 2013; Rout *et al.*, 2013) of those species in the predicted suitable area would be the best option to ensure its future regeneration. Apart from that, the plant functional traits can be used in long-term ecological research to better understand the response of plants to climate change.

Other recommendations would be: improving the quality and status of the databases and maintaining the herbarium with more precise collection localities; conducting more field surveys to accumulate more biological information; using the suitability maps generated from the modelling as baseline data for conservation and prioritization.

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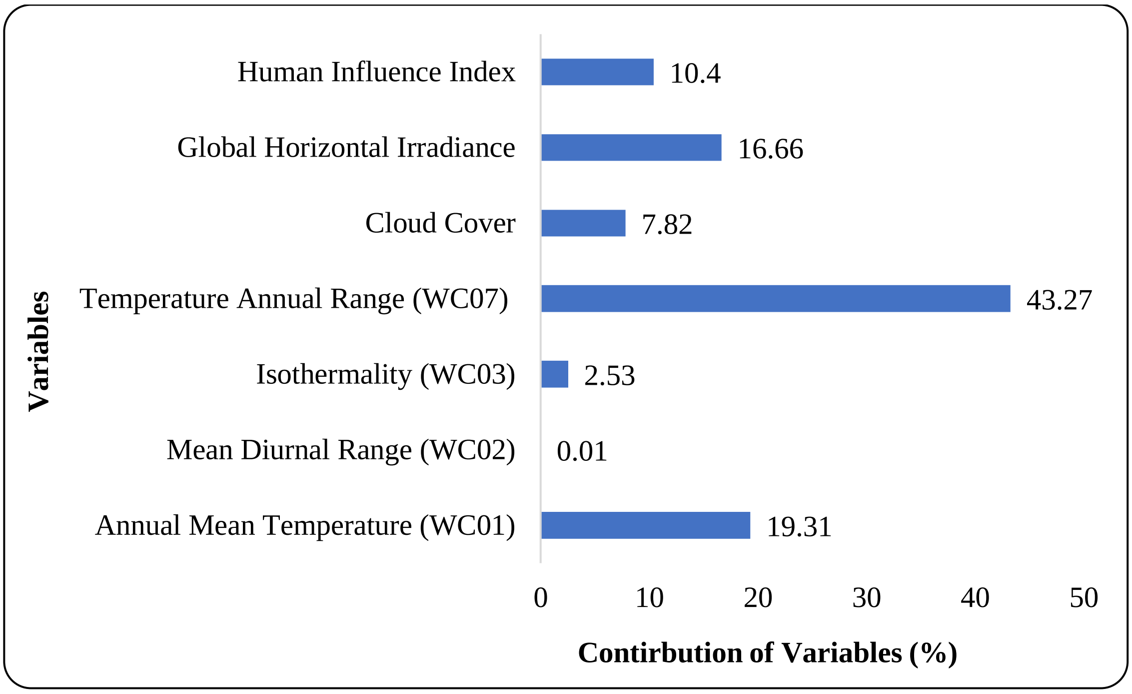
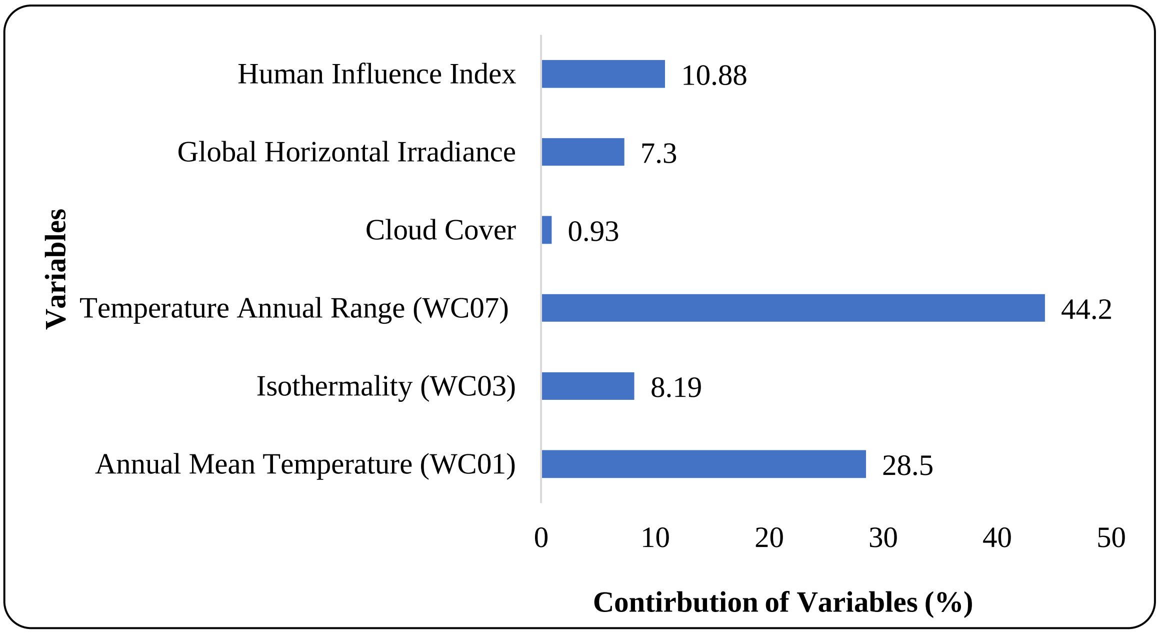
Appendix 1: Contribution of Predictor Variables

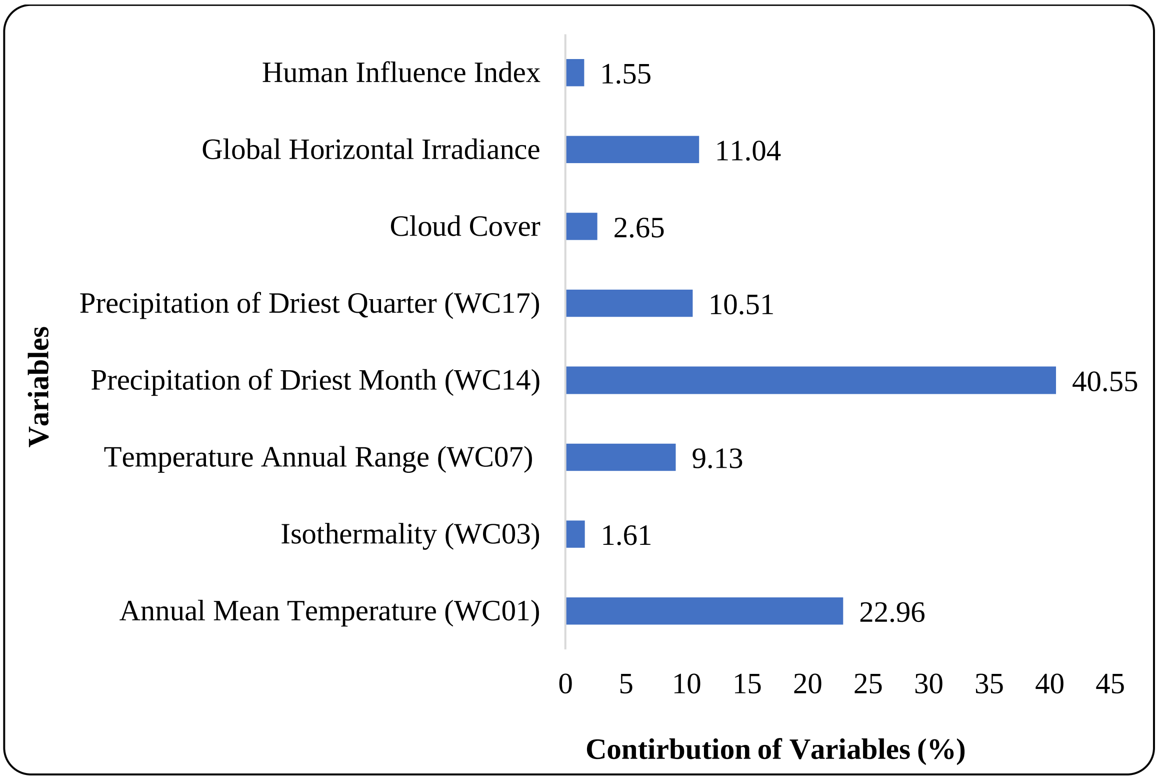


a. Variable Contribution for *Swertia alata*

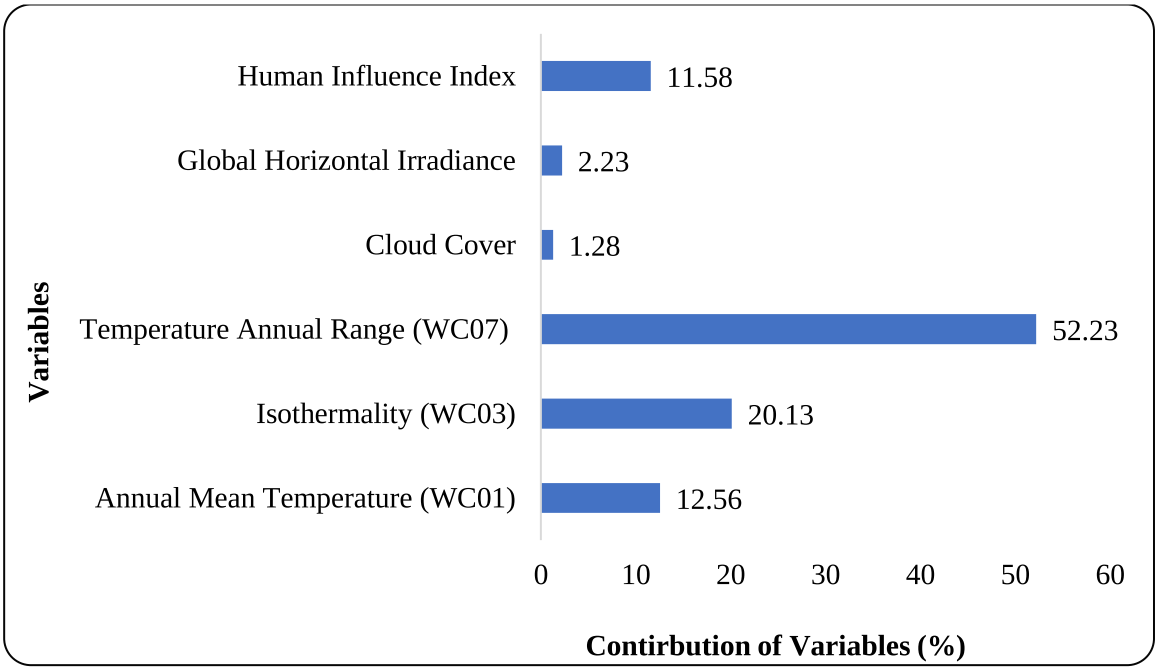


b. Variable Contribution for *Swertia angustifolia*

Appendix 1: Contribution of Predictor Variables (Continue…)

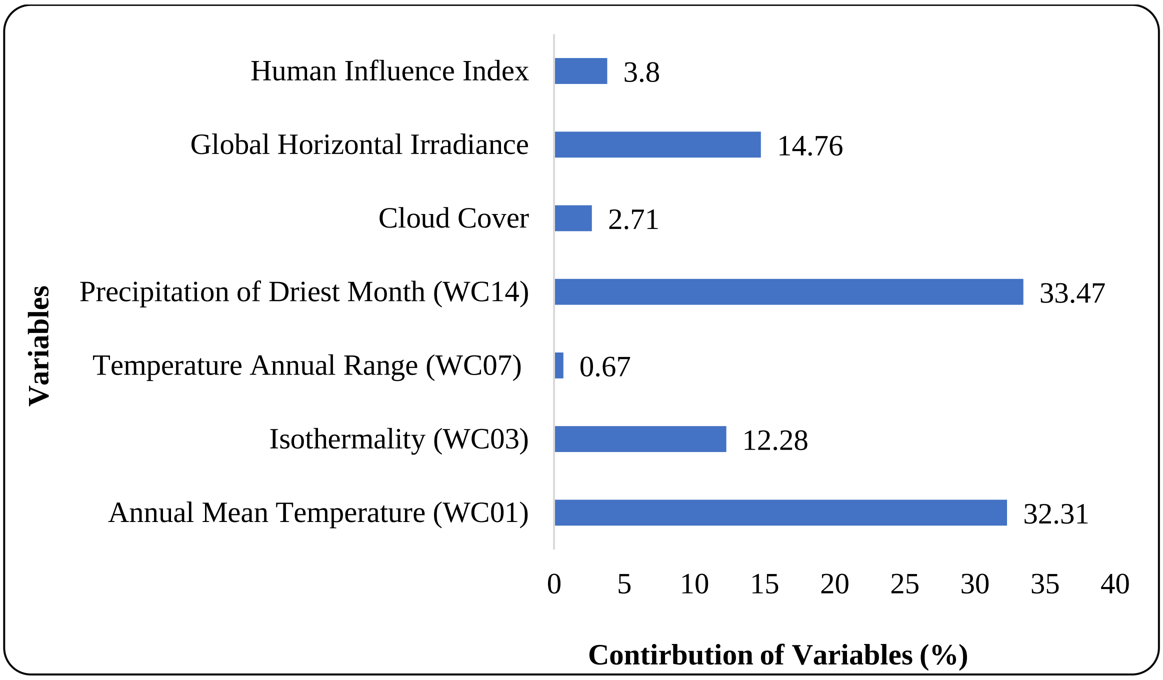


c. Variable Contribution for *Swertia ciliata*

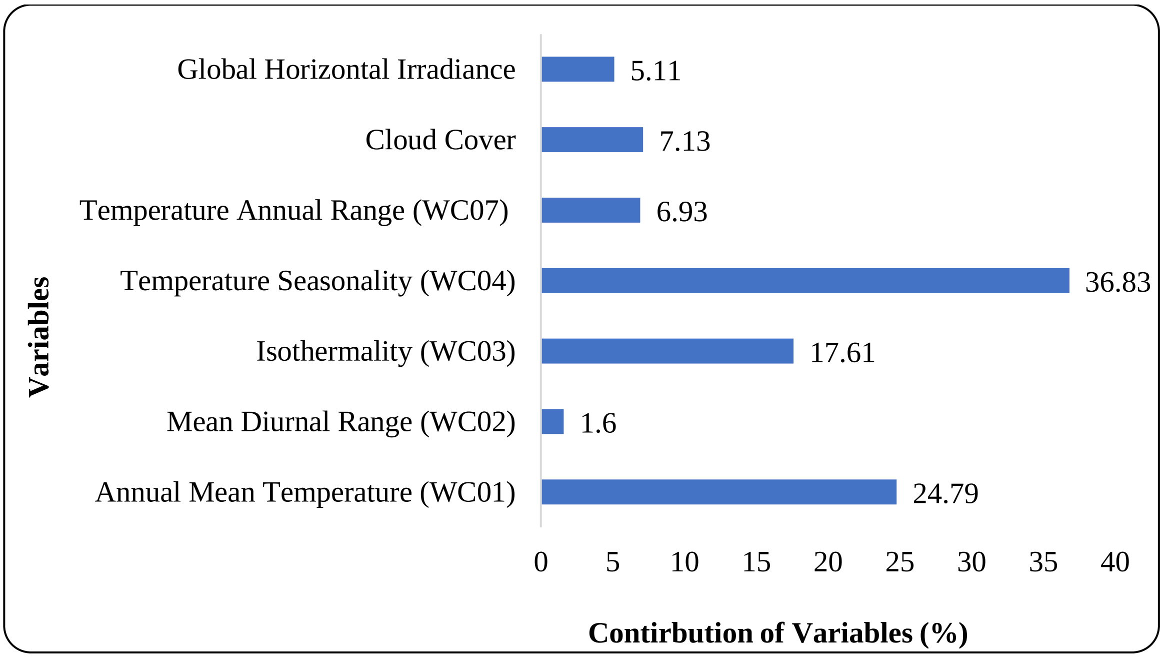


d. Variable Contribution for *Swertia dilatata*

Appendix 1: Contribution of Predictor Variables (Continue…)

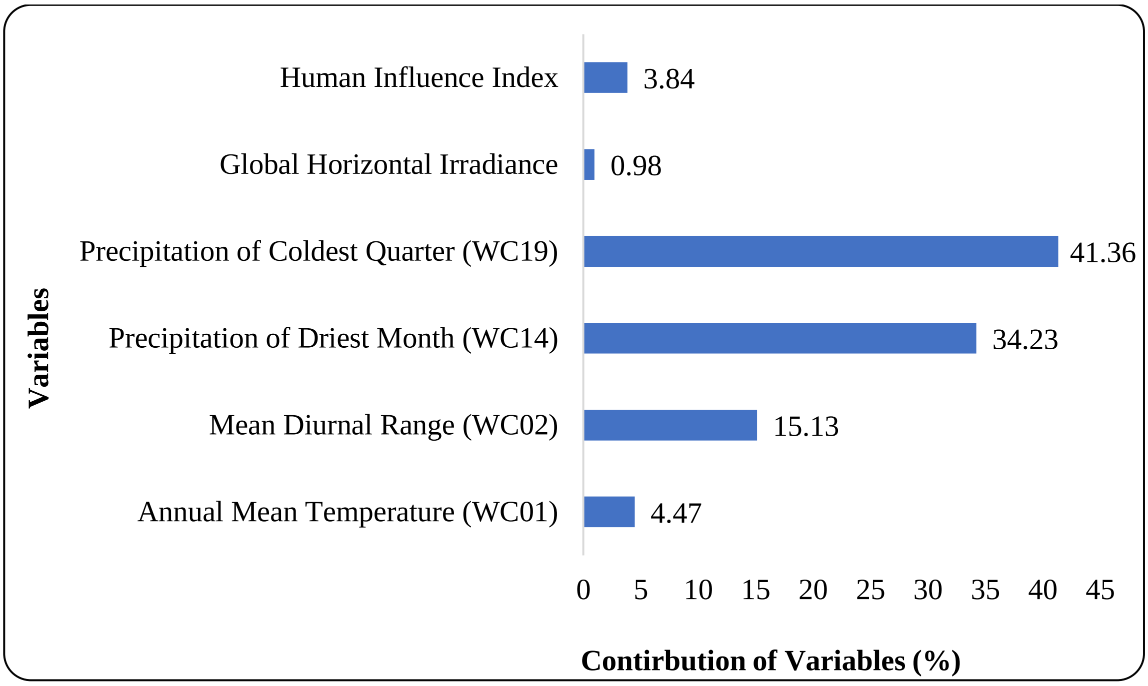


e. Variable Contribution for *Swertia multicaulis*



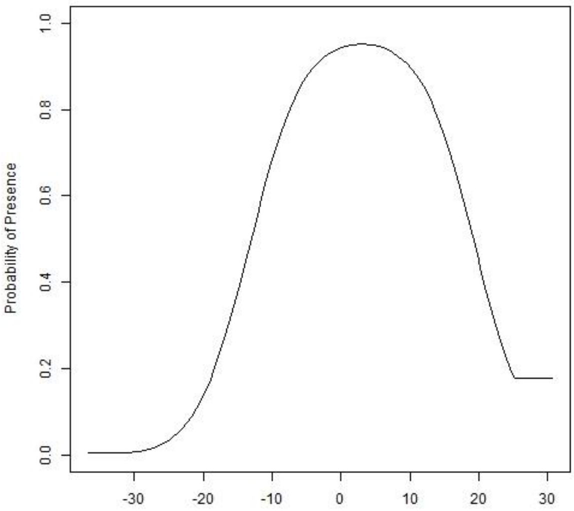
f. Variable Contribution for *Swertia nervosa*

Appendix 1: Contribution of Predictor Variables (Continue…)

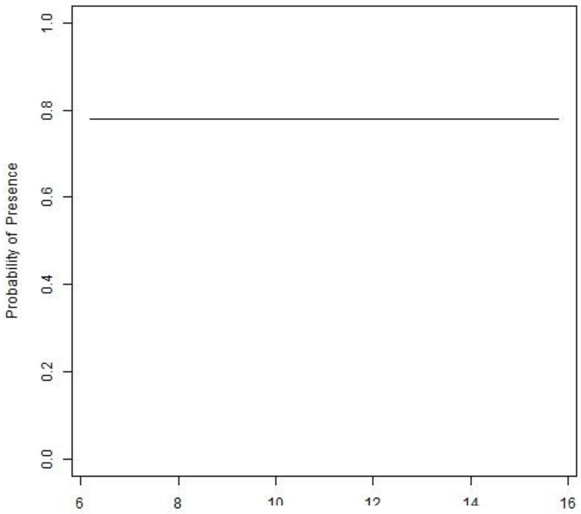


g. Variable Contribution for *Swertia racemosa*

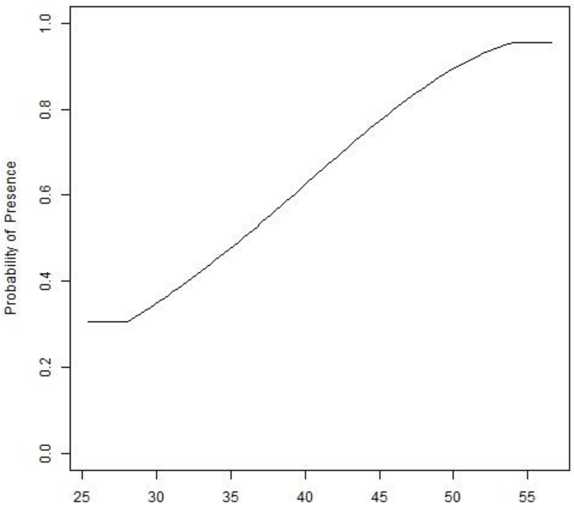
Appendix 2: Response Curves of Predictive Variables for *Swertia alata*



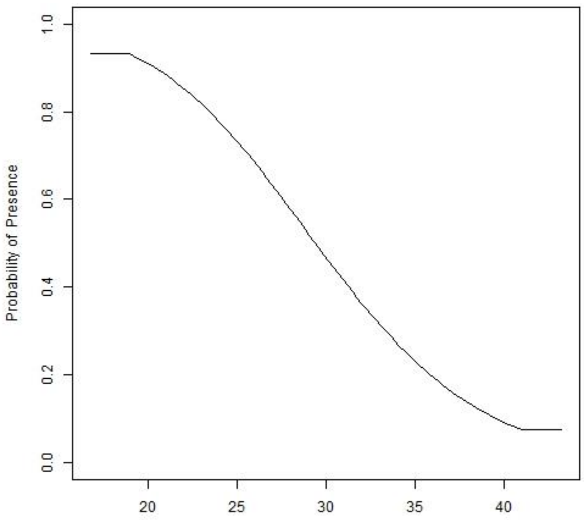
Annual mean temperature



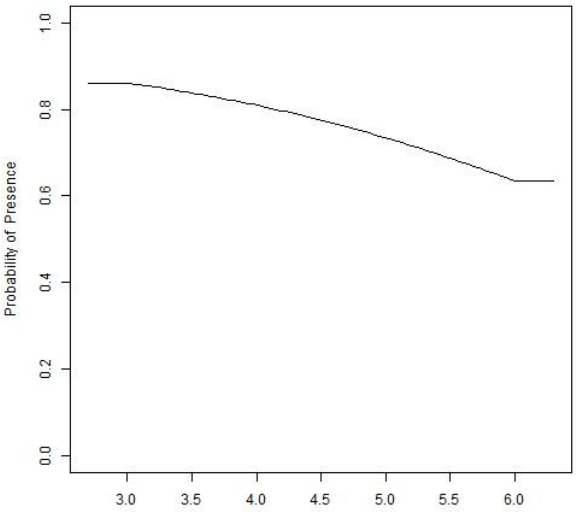
Mean Diurnal Range



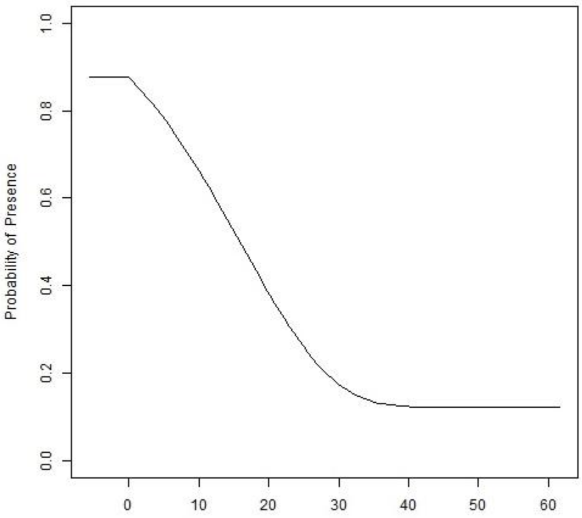
Isothermality



Temperature annual range

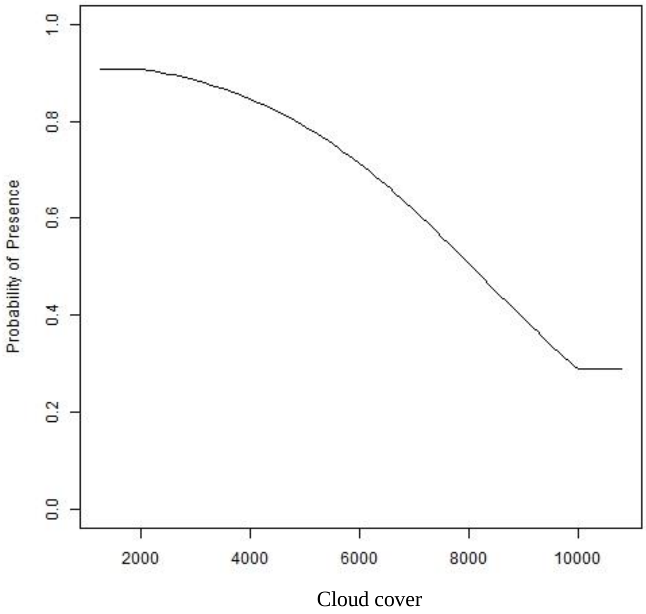


Global horizontal irradiance

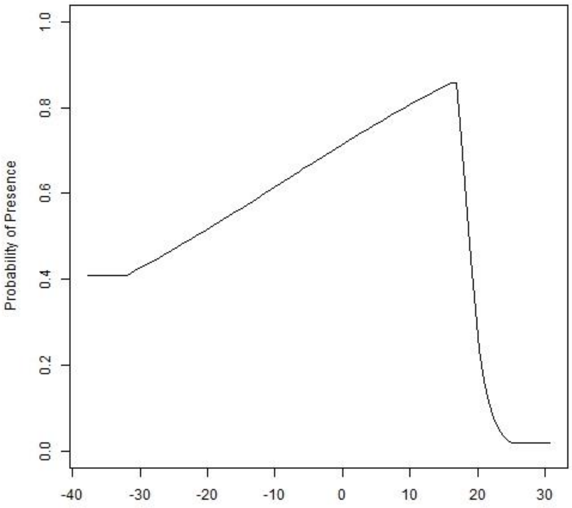


Human influence index

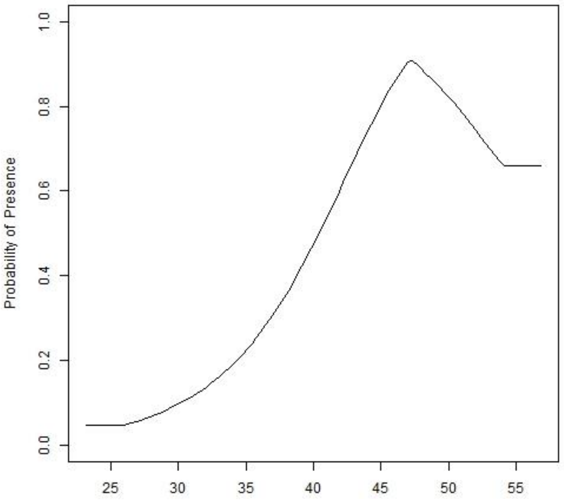
Appendix 2: Response Curves of Predictive Variables for *Swertia alata* (Continue…)



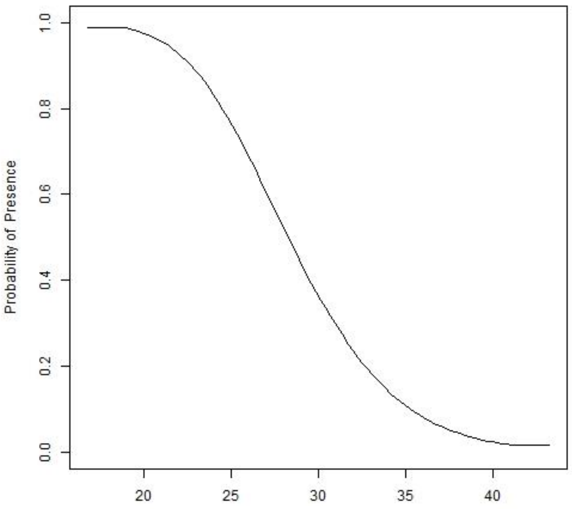
Appendix 3: Response Curves of Predictive Variables for *Swertia angustifolia*



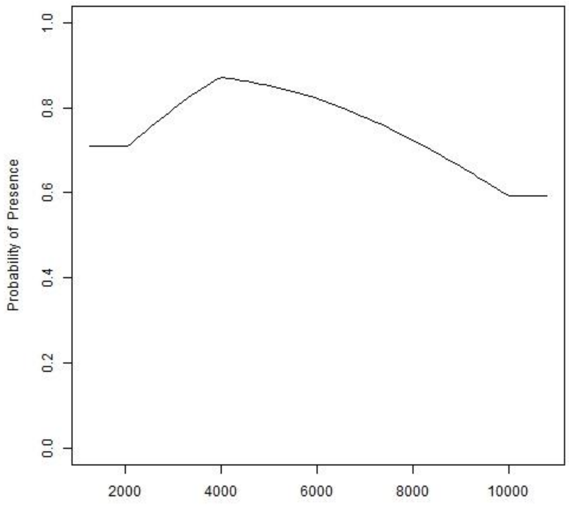
Annual mean temperature



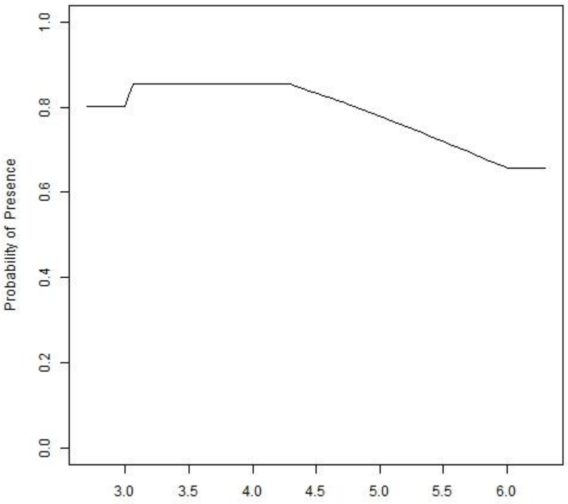
Isothermality



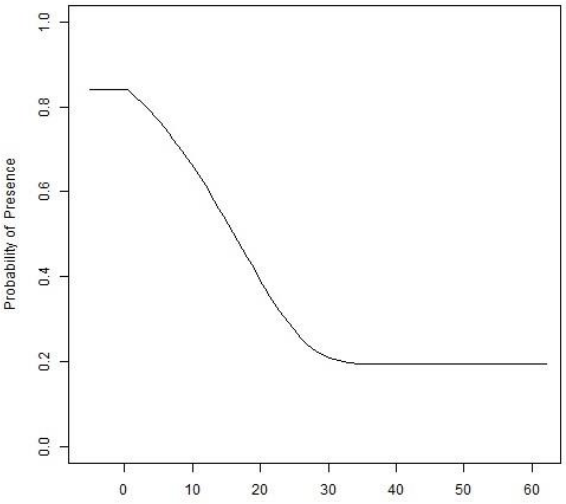
Temperature annual range



Cloud cover

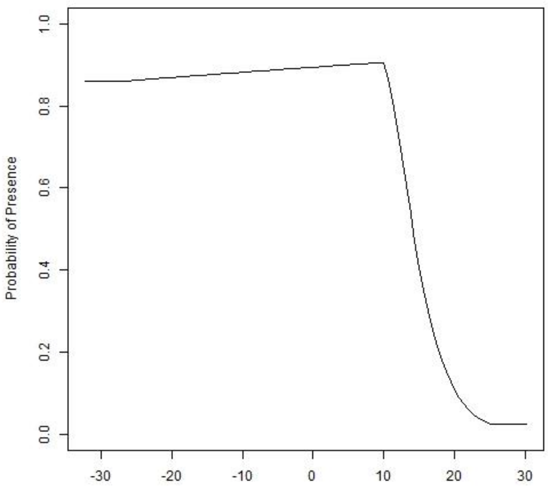


Global horizontal irradiance

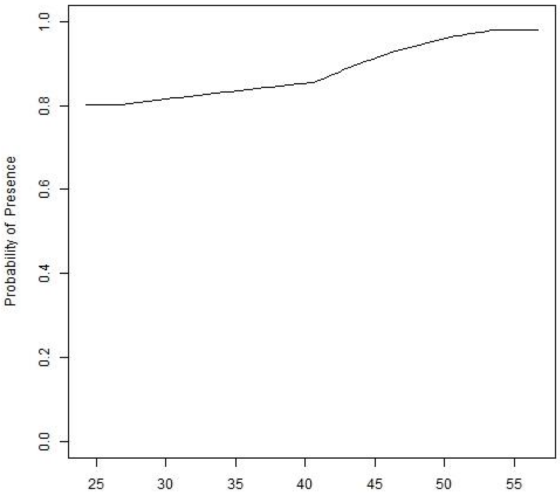


Human influence index

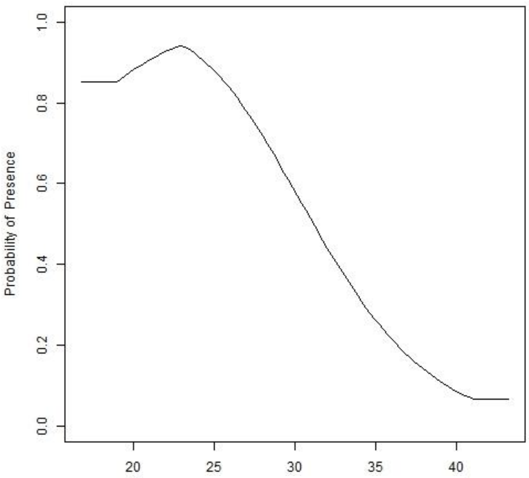
Appendix 4: Response Curves of Predictive Variables for *Swertia ciliata*



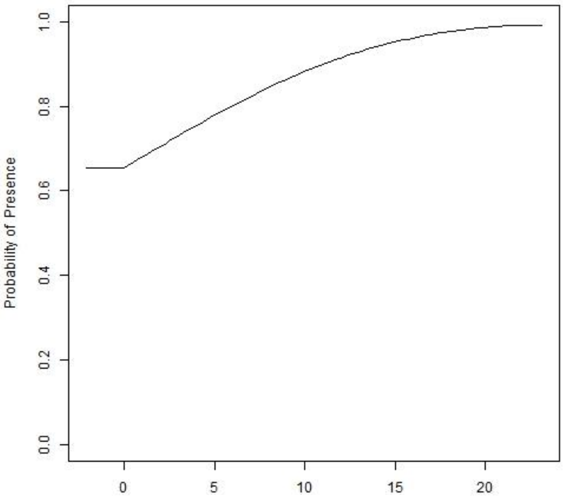
Annual mean temperature



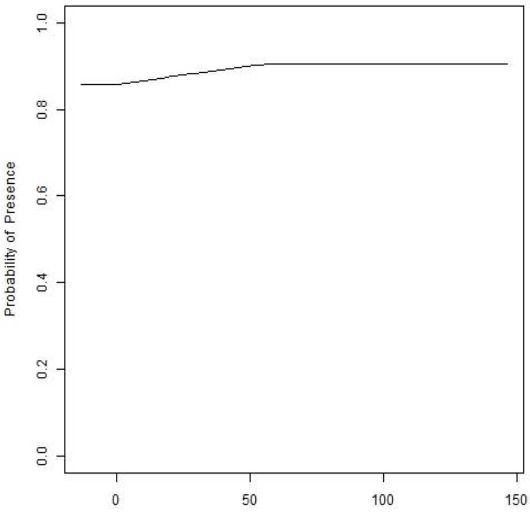
Isothermality



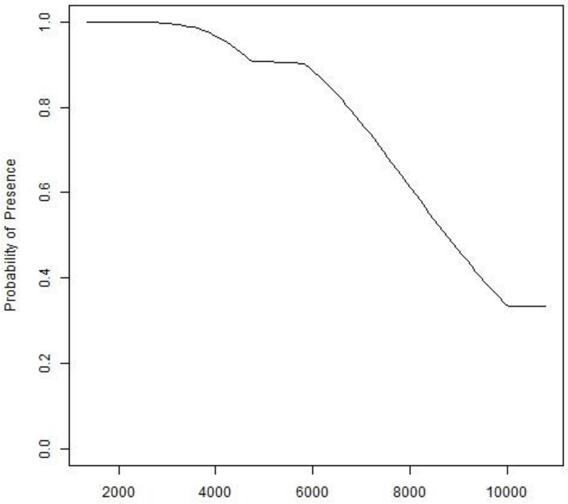
Temperature annual range



Precipitation of driest month

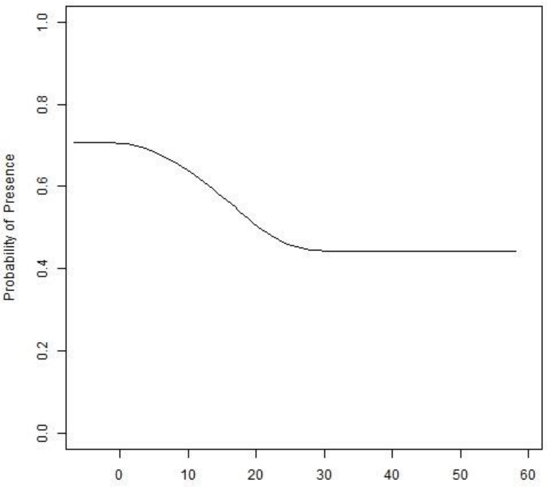


Precipitation of driest quarter

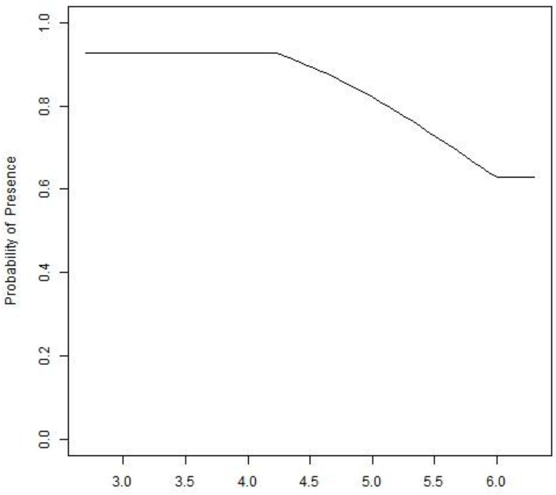


Cloud cover

Appendix 4: Response Curves of Predictive Variables for *Swertia ciliata* (Continue…)

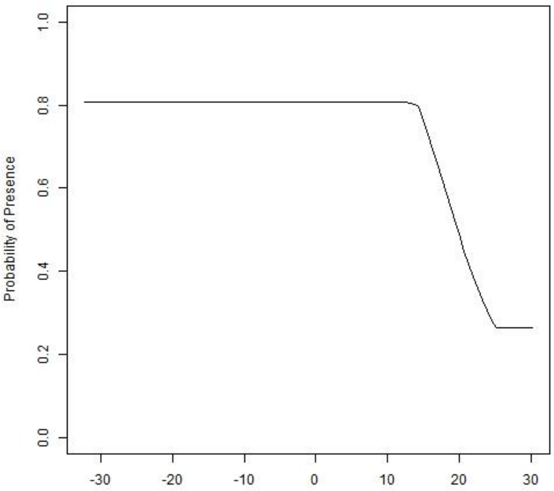


Human influence index

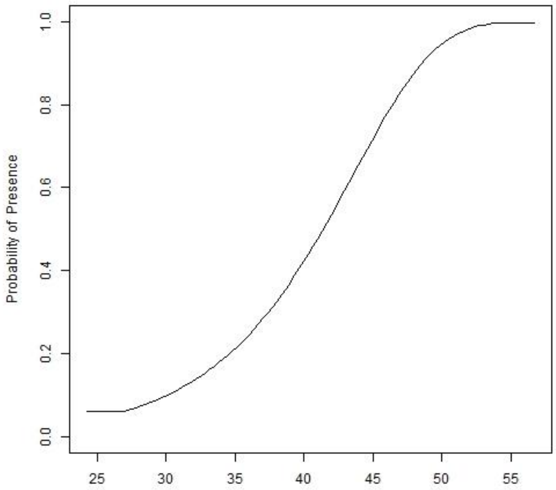


Global horizontal irradiance

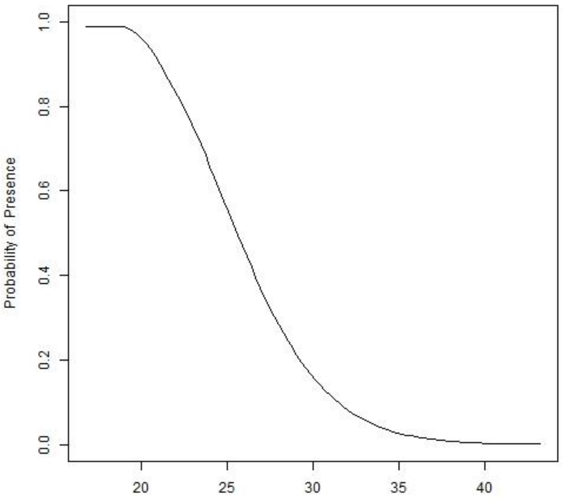
Appendix 5: Response Curves of Predictive Variables for *Swertia dilatata*



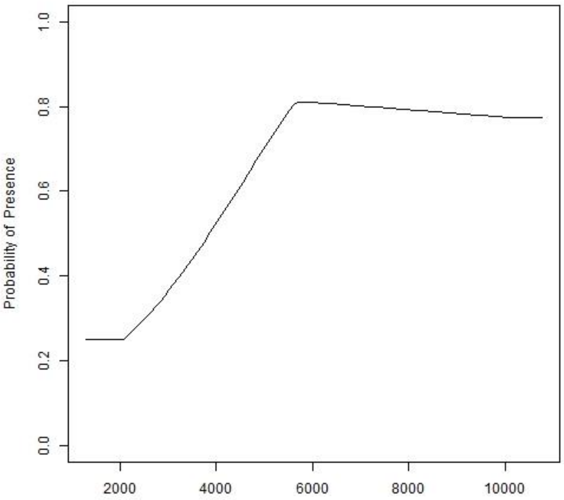
Annual mean temperature



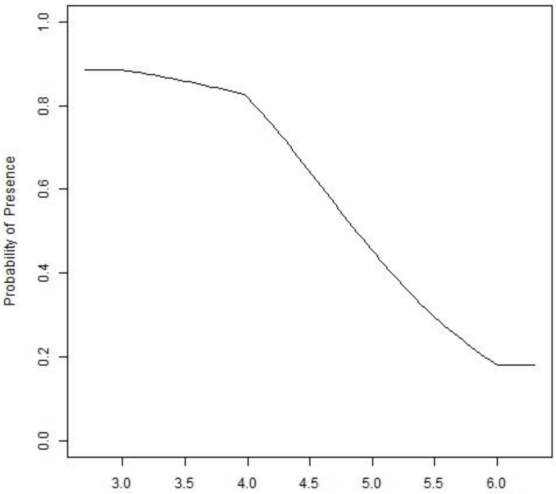
Isothermality



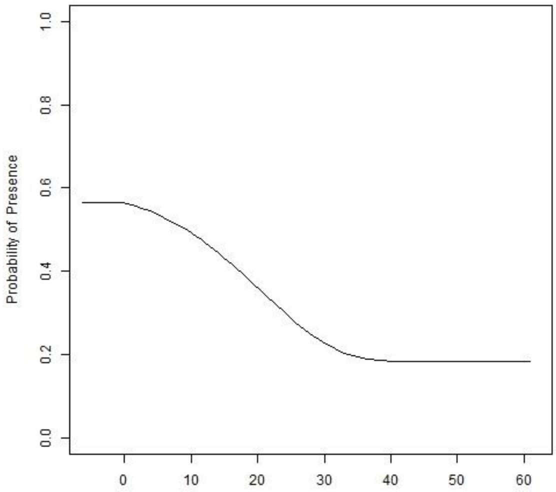
Temperature annaul range



Cloud cover

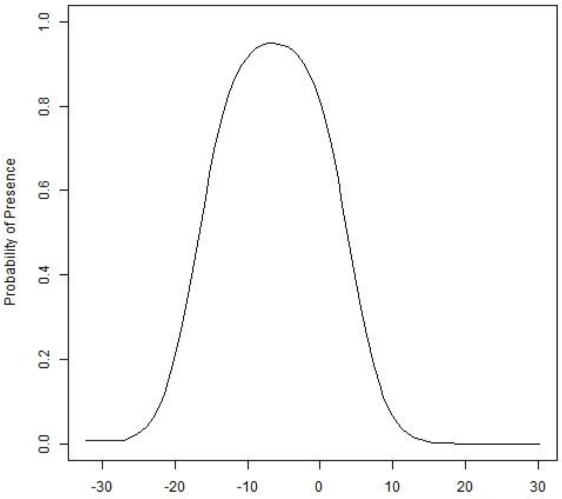


Global horizontal irradiance

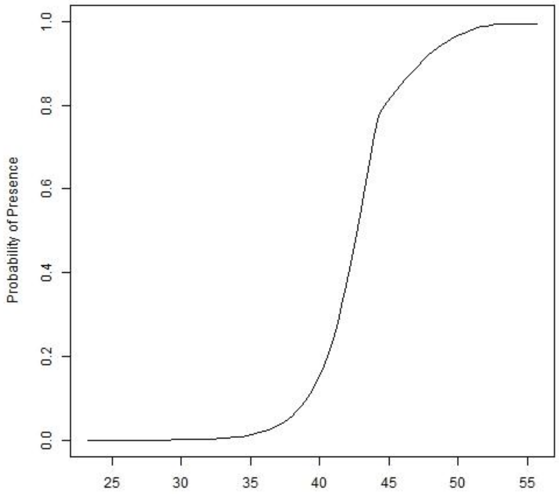


Human influence index

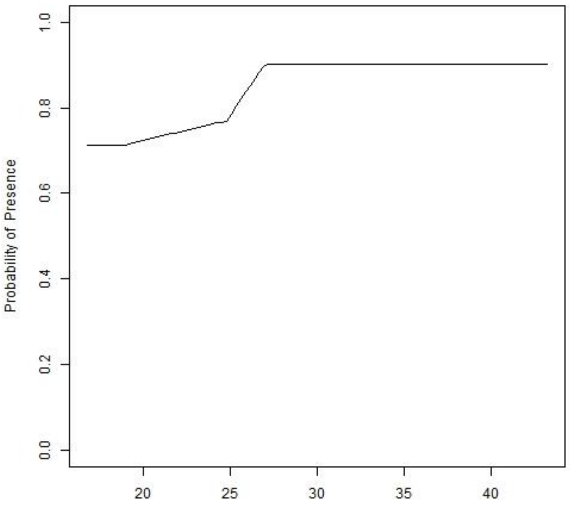
Appendix 6: Response Curves of Predictive Variables for *Swertia multicaulis*



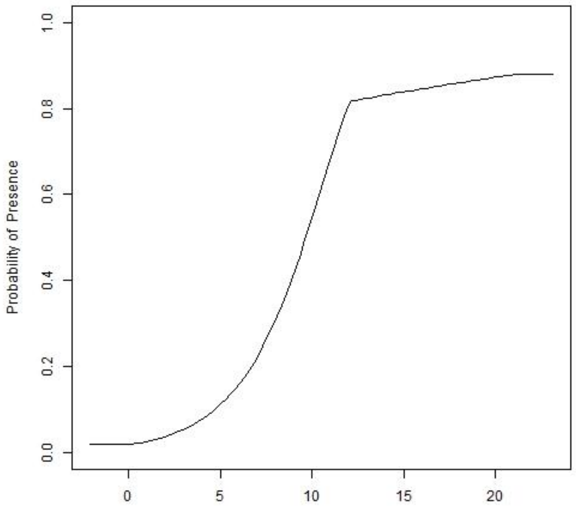
Annual mean temperature



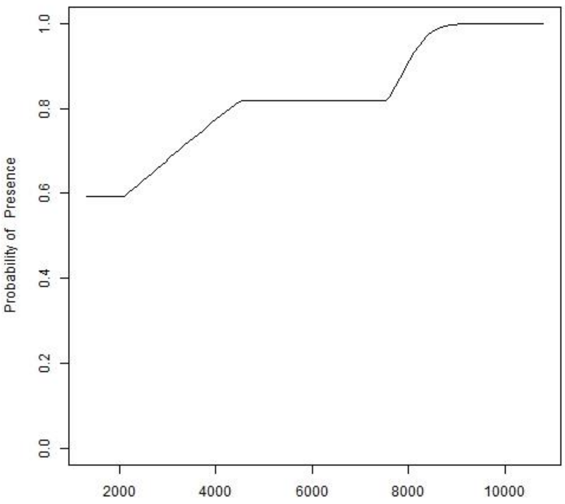
Isothermality



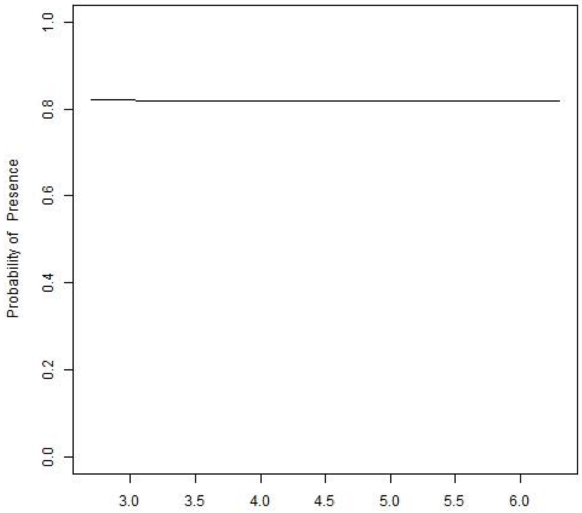
Temperature annual range



Precipitation of driest month

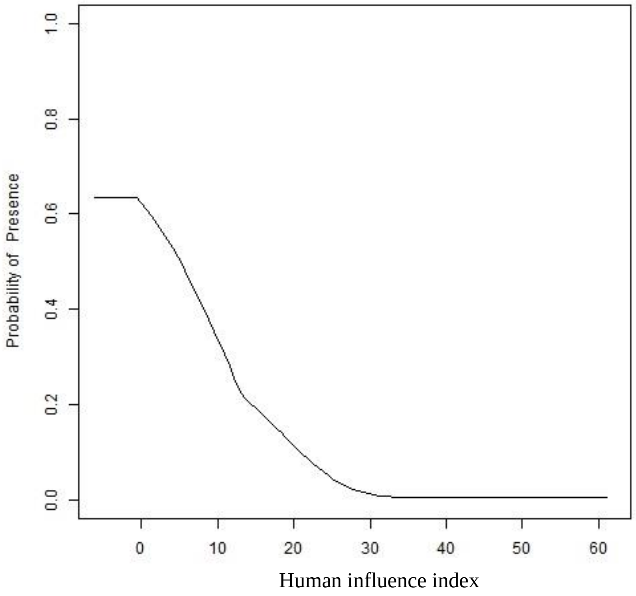


Cloud cover

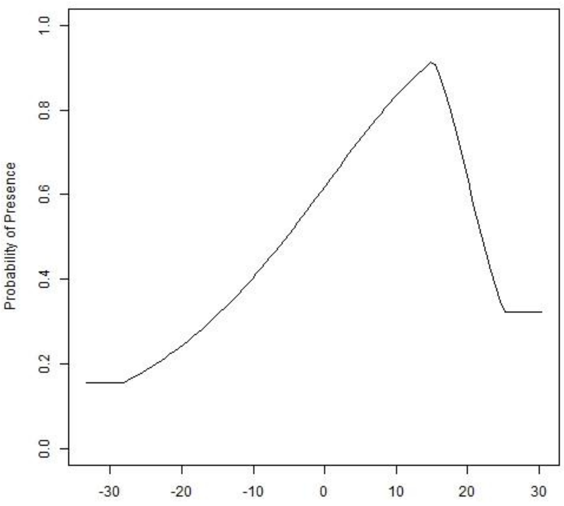


Global horizontal irradiance

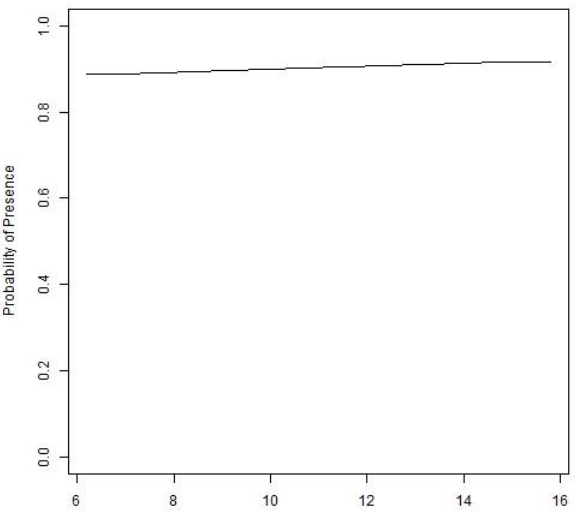
Appendix 6: Response Curves of Predictive Variables for *Swertia multicaulis* (Continue…)



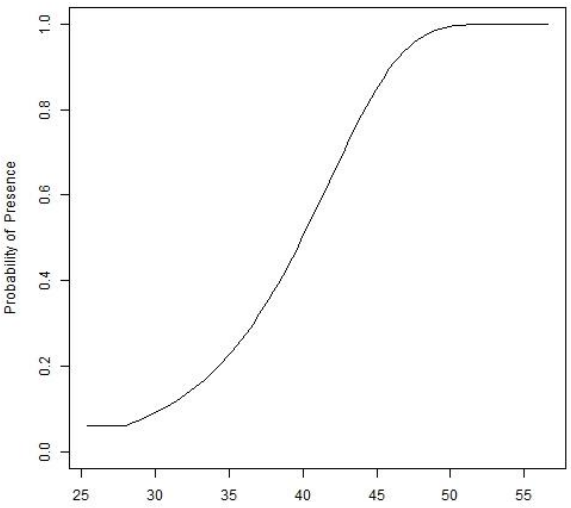
Appendix 7: Response Curves of Predictive Variables for *Swertia nervosa*



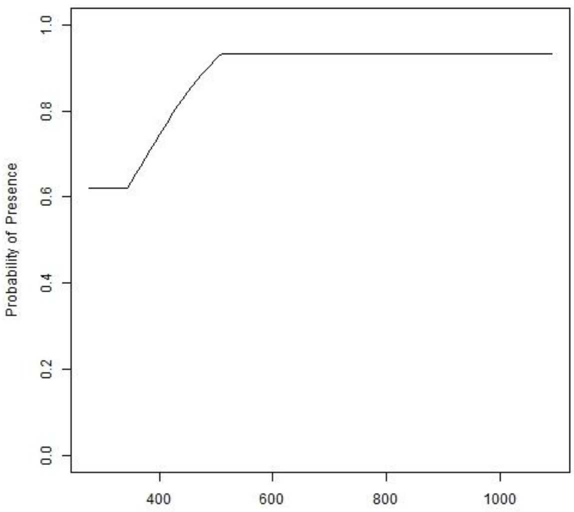
Annual mean temperature



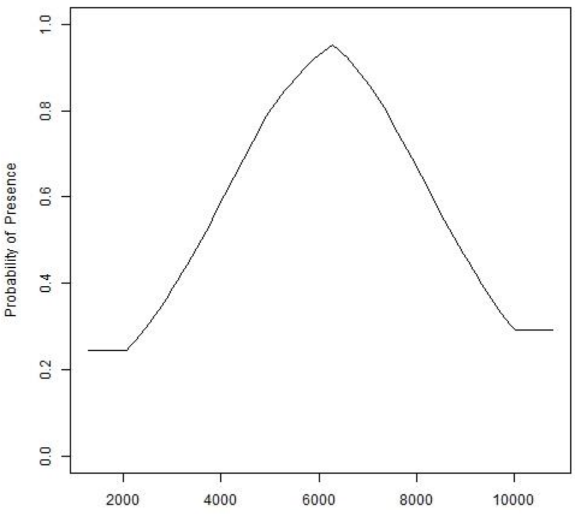
Mean diurnal range



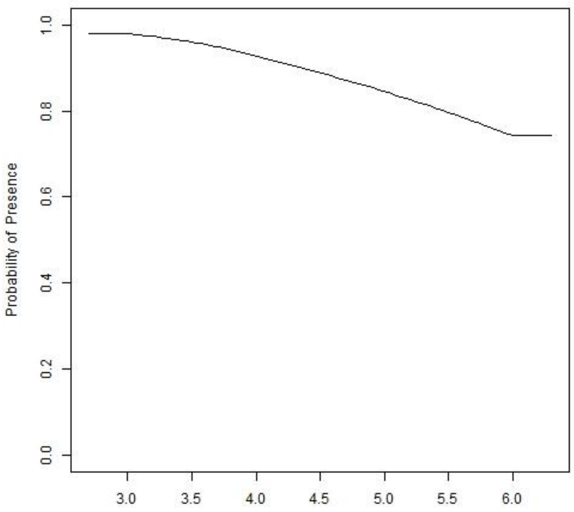
Isothermality



Temperature seasonality

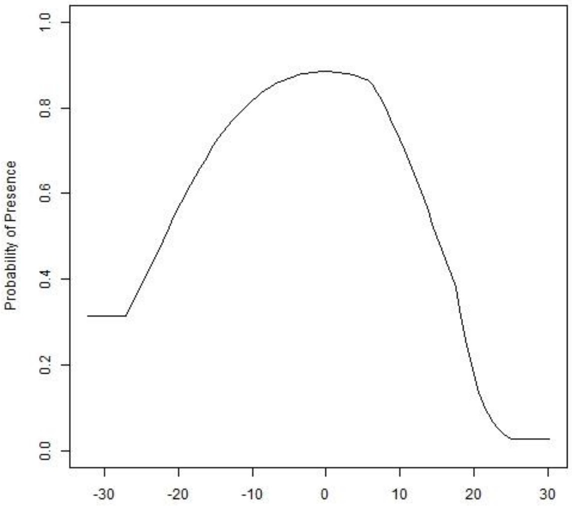


Cloud cover

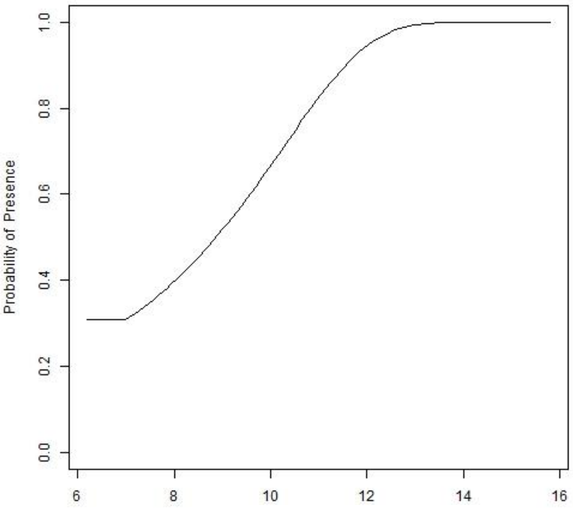


Global horizontal irradiance

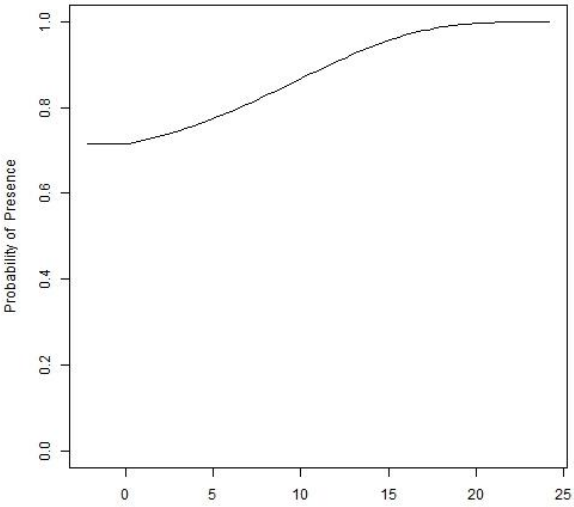
Appendix 8: Response Curves of Predictive Variables for *Swertia racemosa*



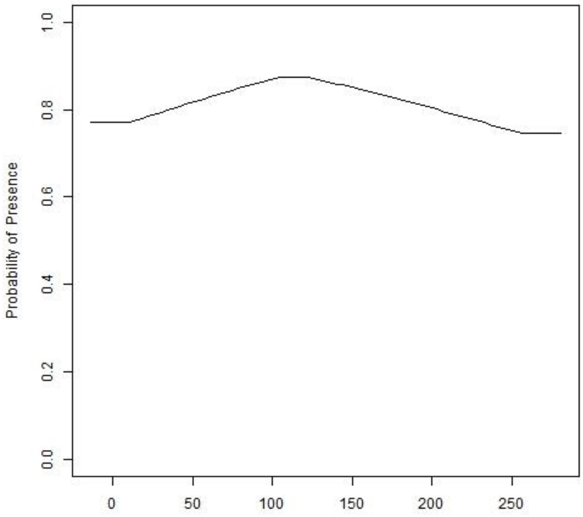
Annual mean temperature



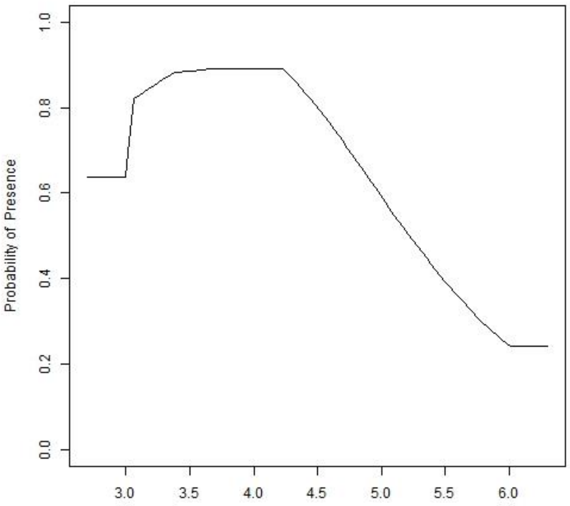
Mean diurnal range



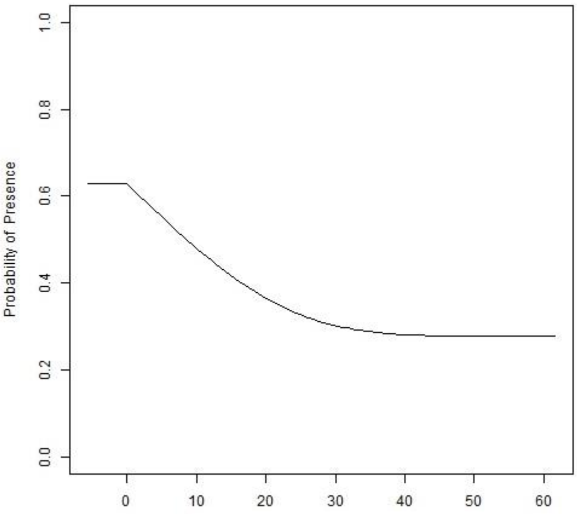
Precipitation of driest month



Precipitation of coldest quarter

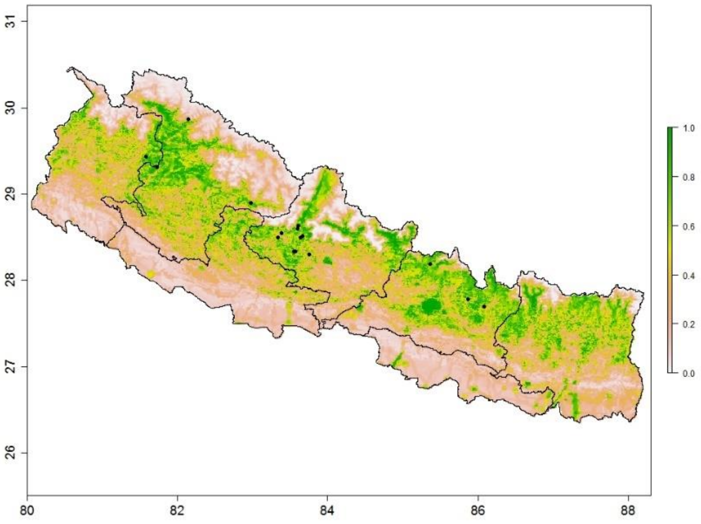


Global horizontal irradiance

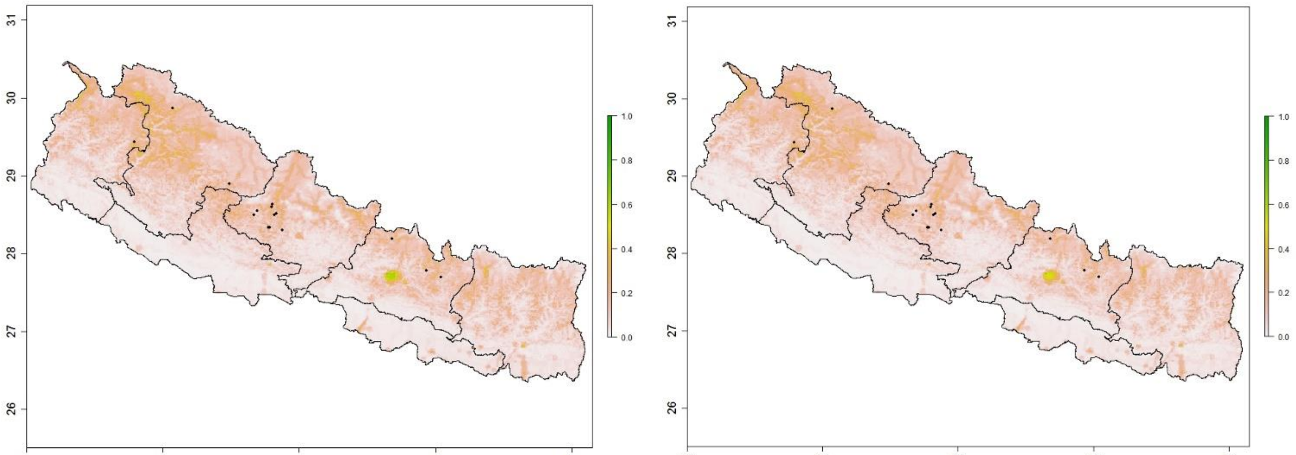


Human influence index

Appendix 9: Habitat Suitability Map of *Swertia alata* under Current and Future Climate Scenarios

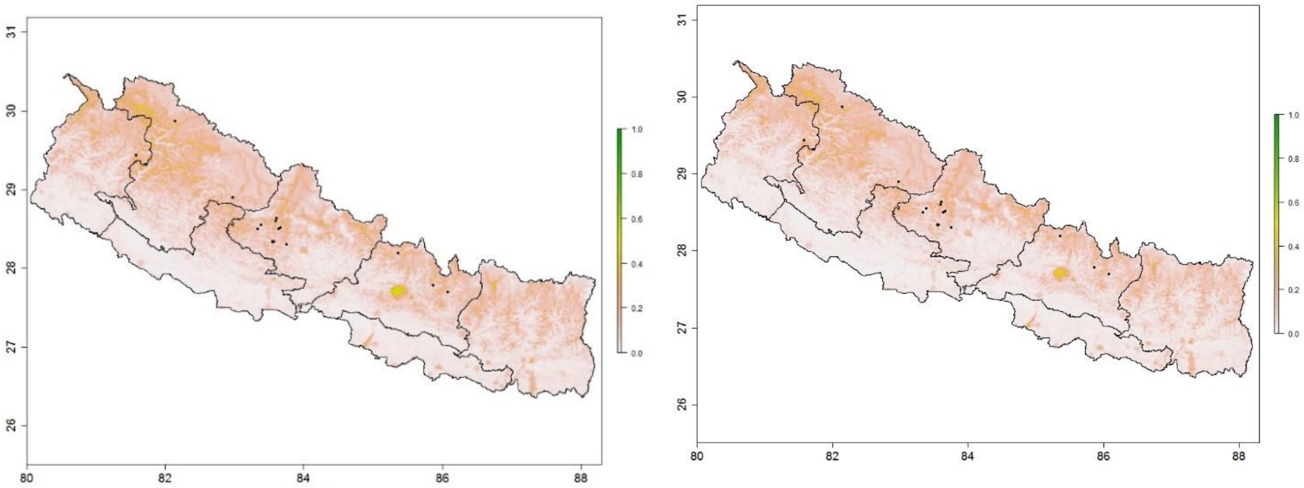


a. Habitat suitability under current climate



b. Habitat suitability in 2050 (RCP 6)

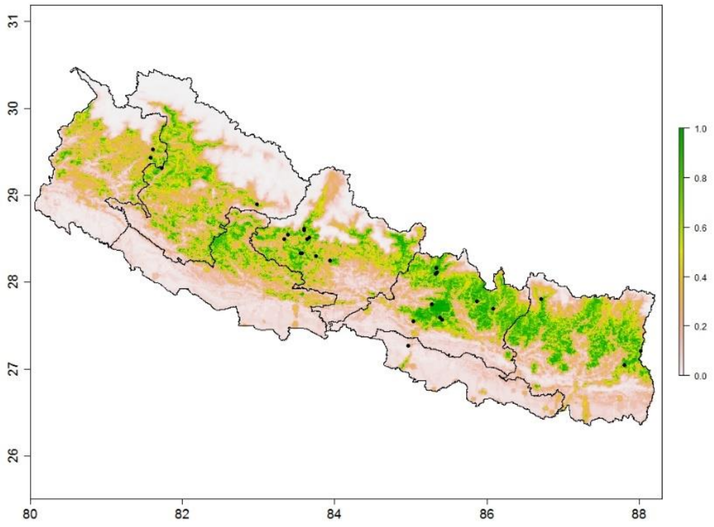
c. Habitat suitability in 2070 (RCP 6)



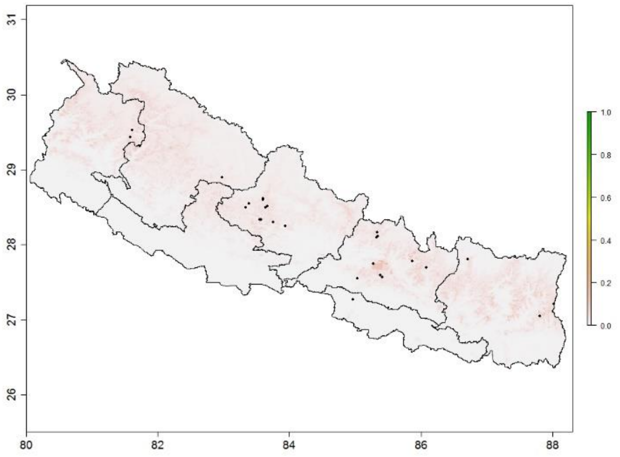
d. Habitat suitability in 2050 (RCP 8.5)

e. Habitat suitability in 2070 (RCP 8.5)

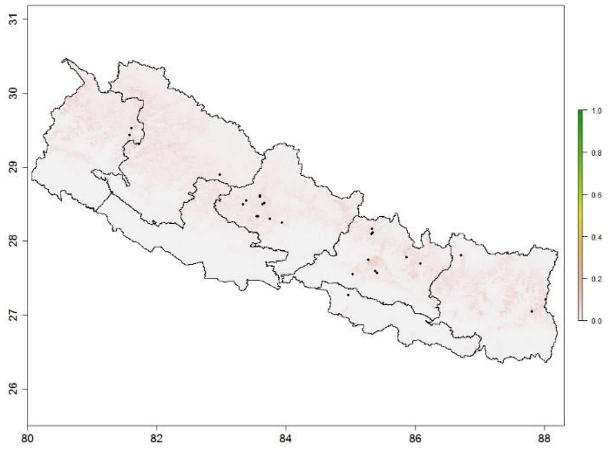
Appendix 10: Habitat Suitability Map of *Swertia angustifolia* under Current and Future Climate Scenarios



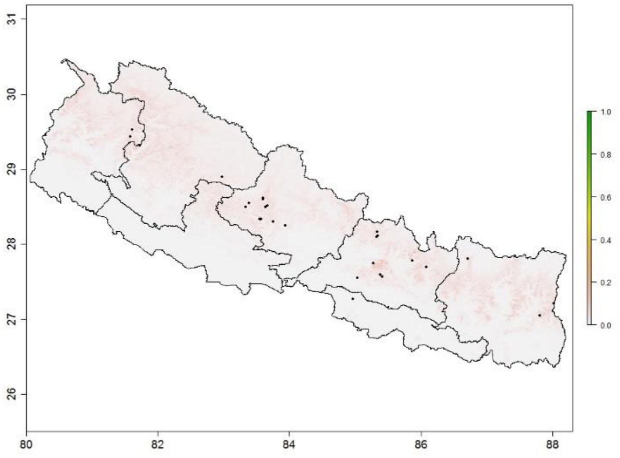
a. Habitat suitability under current climate



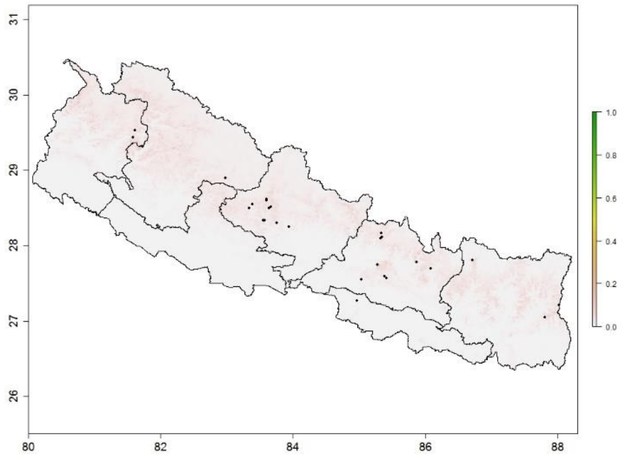
b. Habitat suitability in 2050 (RCP 6)



c. Habitat suitability in 2070 (RCP 6)

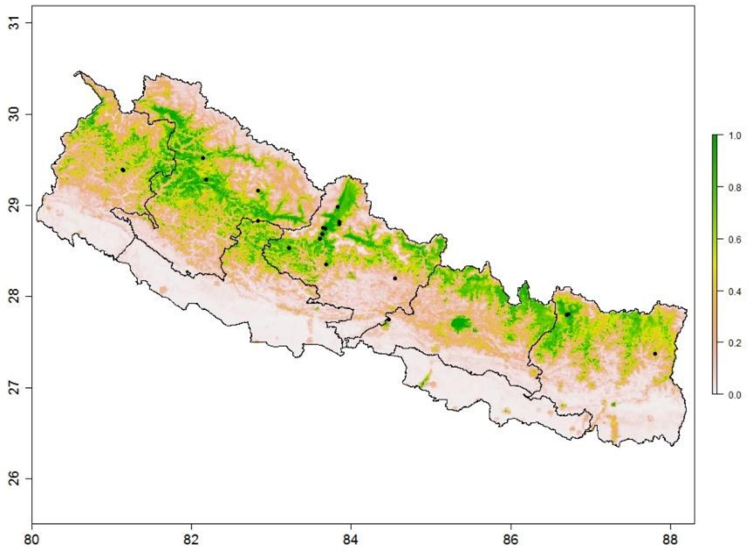


d. Habitat suitability in 2050 (RCP 8.5)

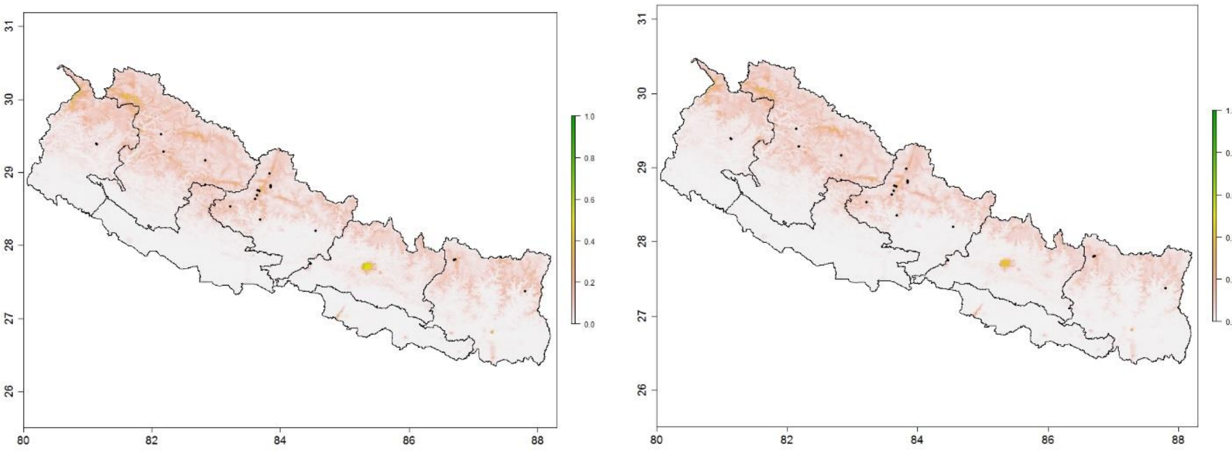


e. Habitat suitability in 2070 (RCP 8.5)

Appendix 11: Habitat Suitability Map of *Swertia ciliata* under Current and Future Climate Scenarios

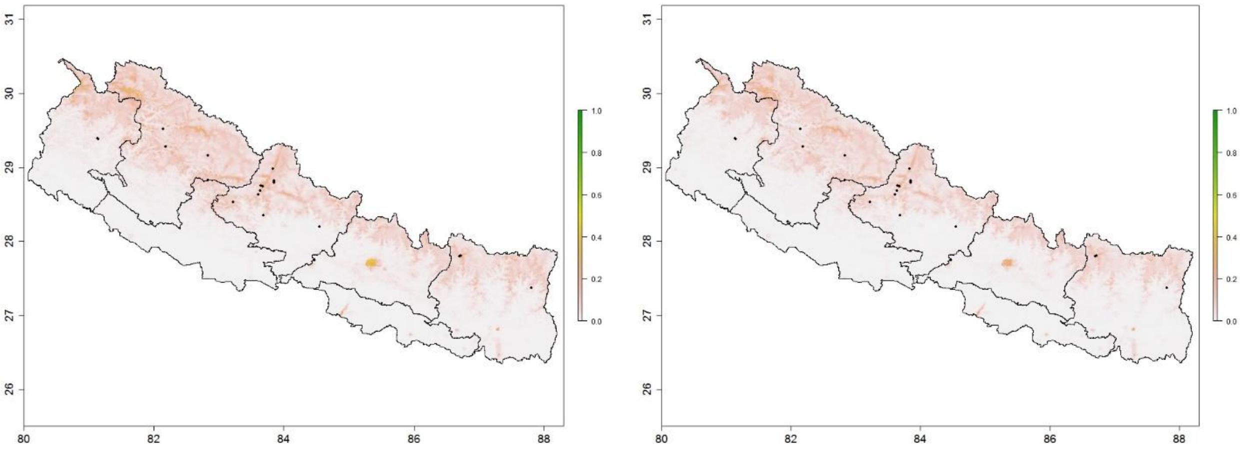


a. Habitat suitability under current climate



b. Habitat suitability in 2050 (RCP 6)

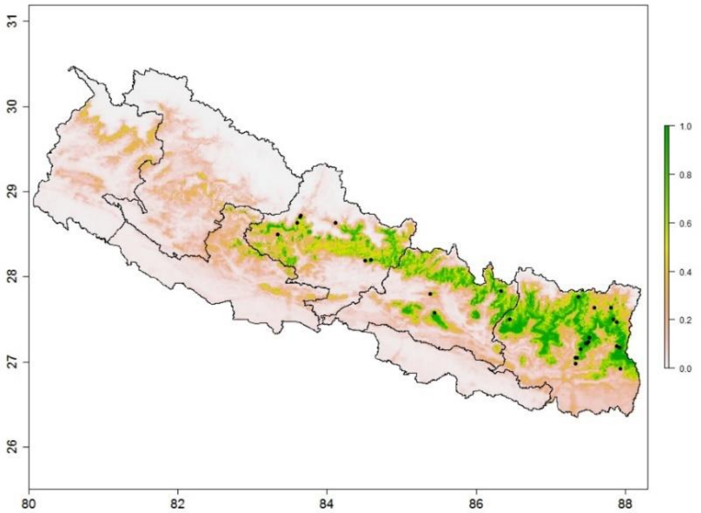
c. Habitat suitability in 2070 (RCP 6)



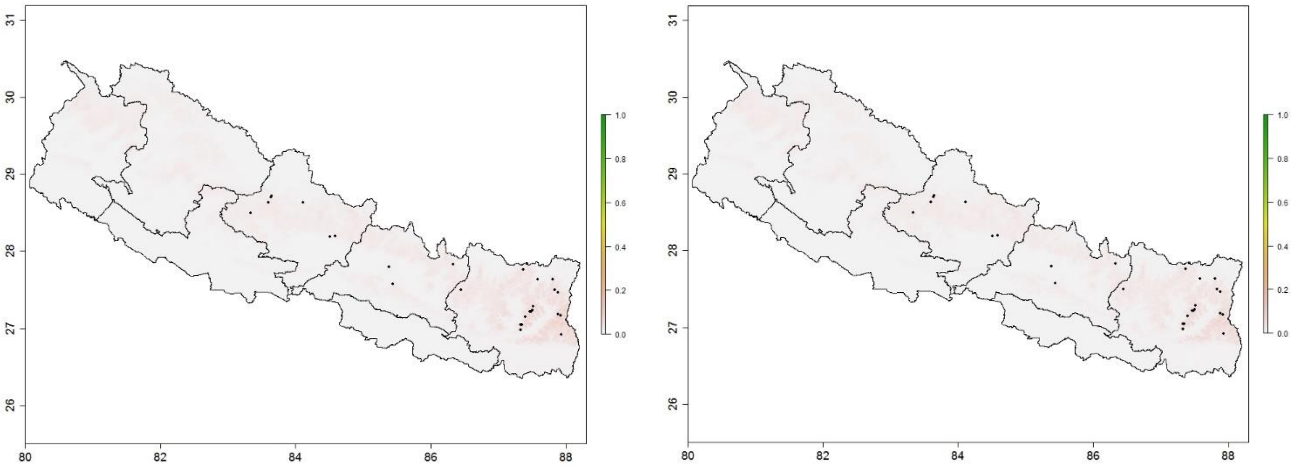
d. Habitat suitability in 2050 (RCP 8.5)

e. Habitat suitability in 2070 (RCP 8.5)

Appendix 12: Habitat Suitability Map of *Swertia dilatata* under Current and Future Climate Scenarios

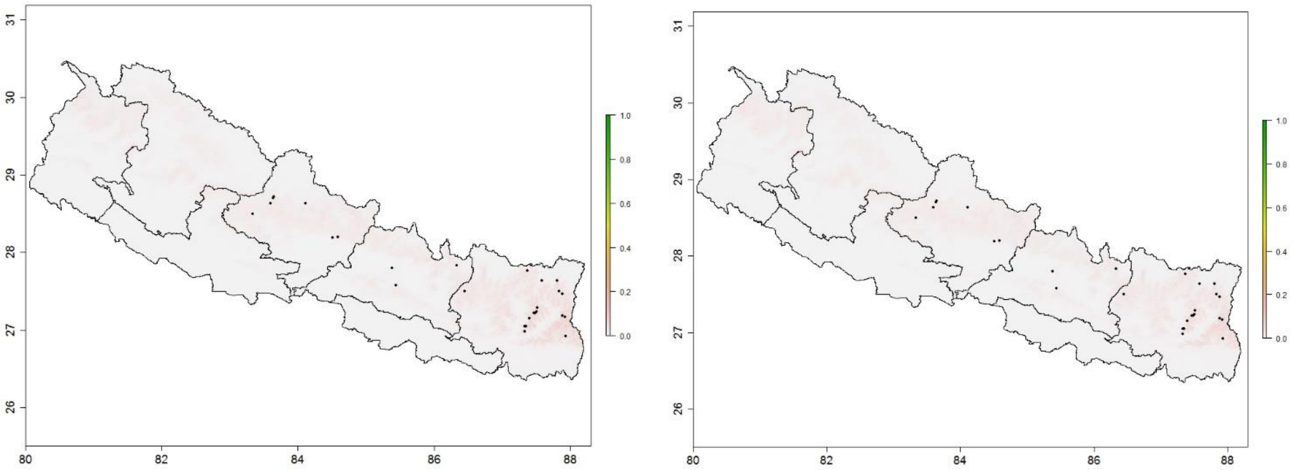


a. Habitat suitability under current climate



b. Habitat suitability in 2050 (RCP 6)

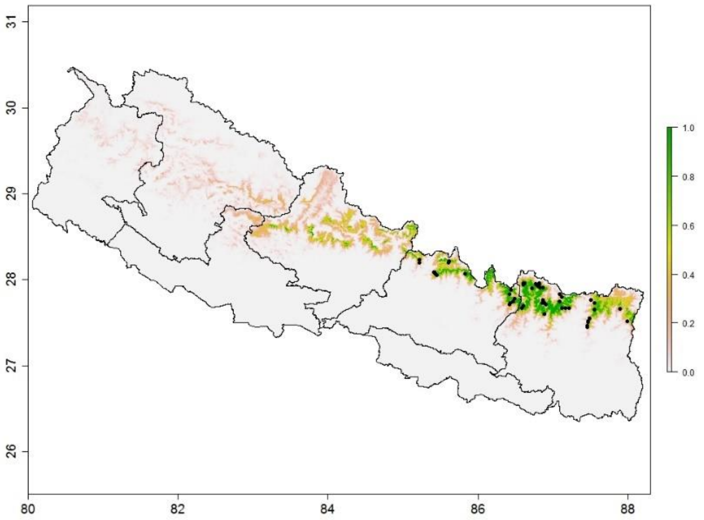
c. Habitat suitability in 2070 (RCP 6)



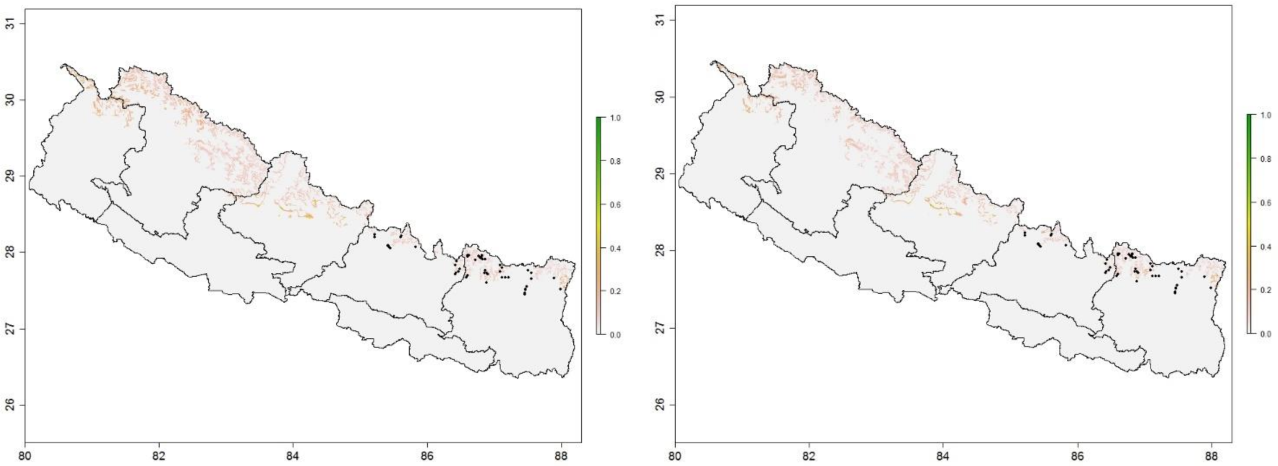
d. Habitat suitability in 2050 (RCP 8.5)

e. Habitat suitability in 2070 (RCP 8.5)

Appendix 13: Habitat Suitability Map of *Swertia multicaulis* under Current and Future Climate Scenarios

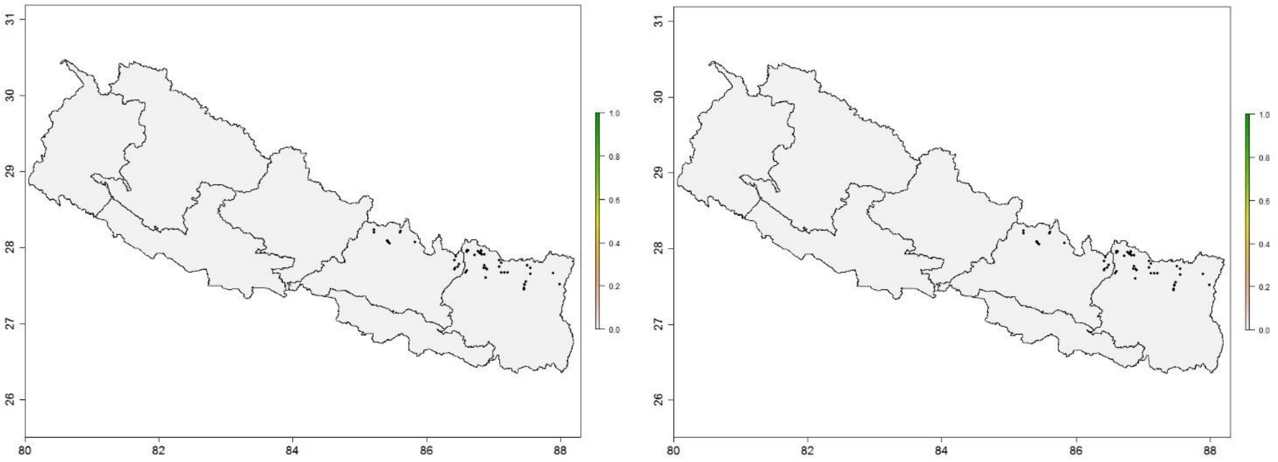


a. Habitat suitability under current climate



b. Habitat suitability in 2050 (RCP 6)

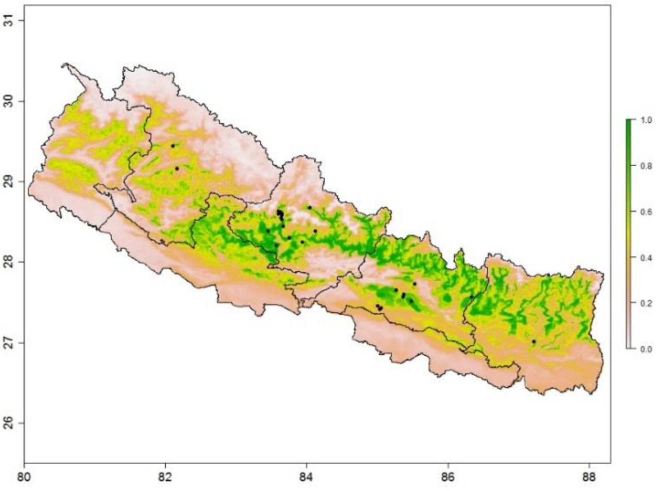
c. Habitat suitability in 2070 (RCP 6)



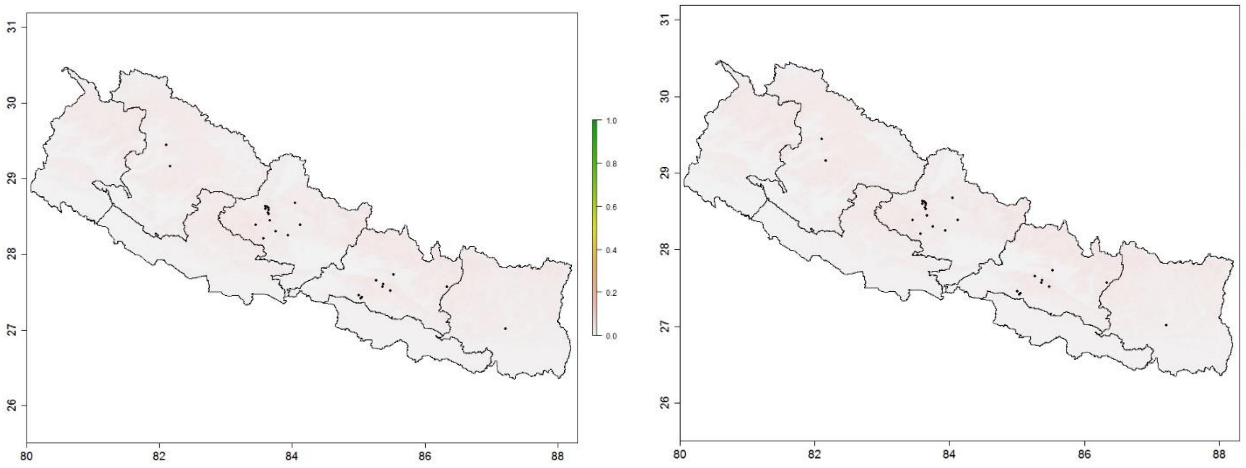
d. Habitat suitability in 2050 (RCP 8.5)

e. Habitat suitability in 2070 (RCP 8.5)

Appendix 14: Habitat Suitability Map of *Swertia nervosa* under Current and Future Climate Scenarios

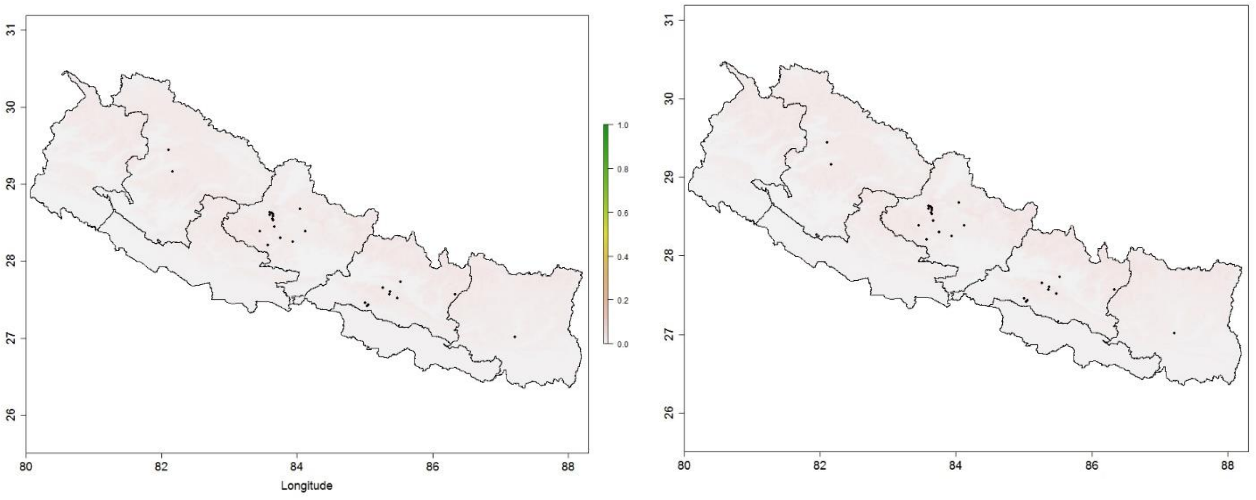


a. Habitat suitability under current climate



b. Habitat suitability in 2050 (RCP 6)

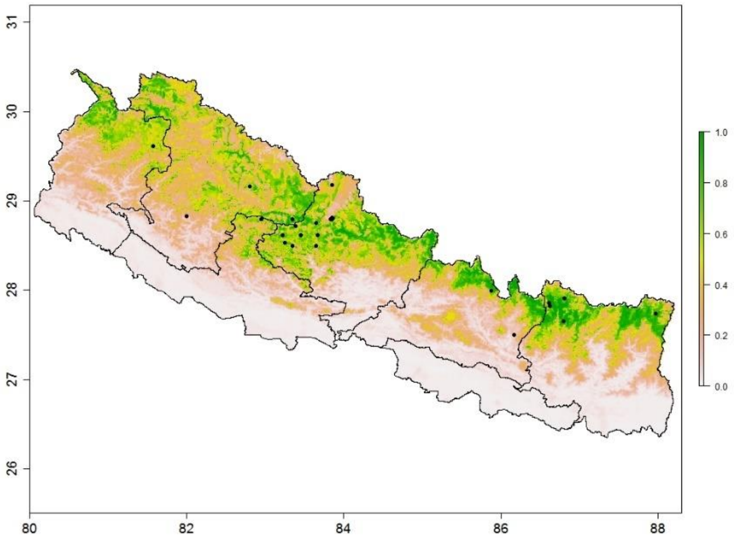
c. Habitat suitability in 2070 (RCP 6)



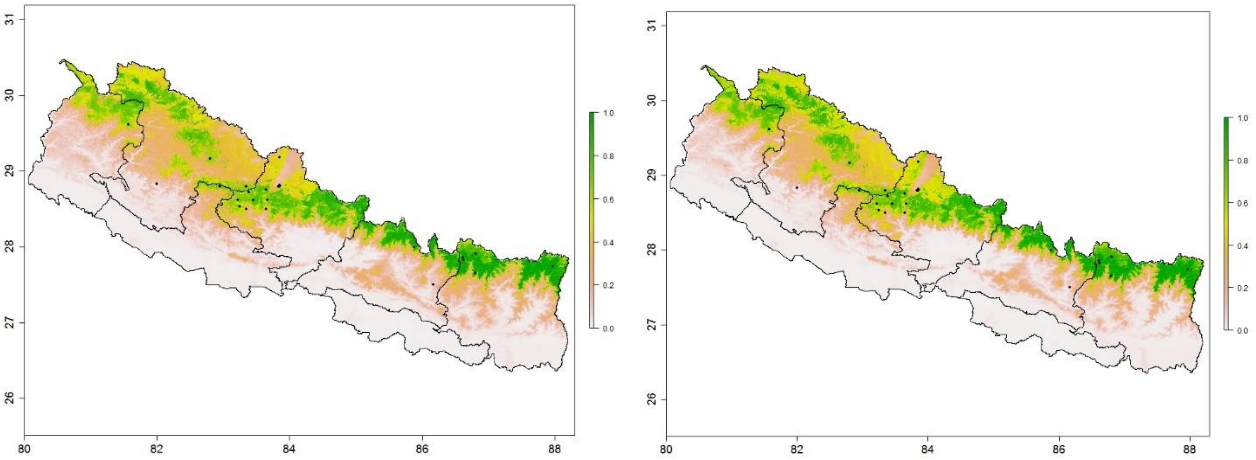
d. Habitat suitability in 2050 (RCP 8.5)

e. Habitat suitability in 2070 (RCP 8.5)

Appendix 15: Habitat Suitability Map of *Swertia racemosa* under Current and Future Climate Scenarios

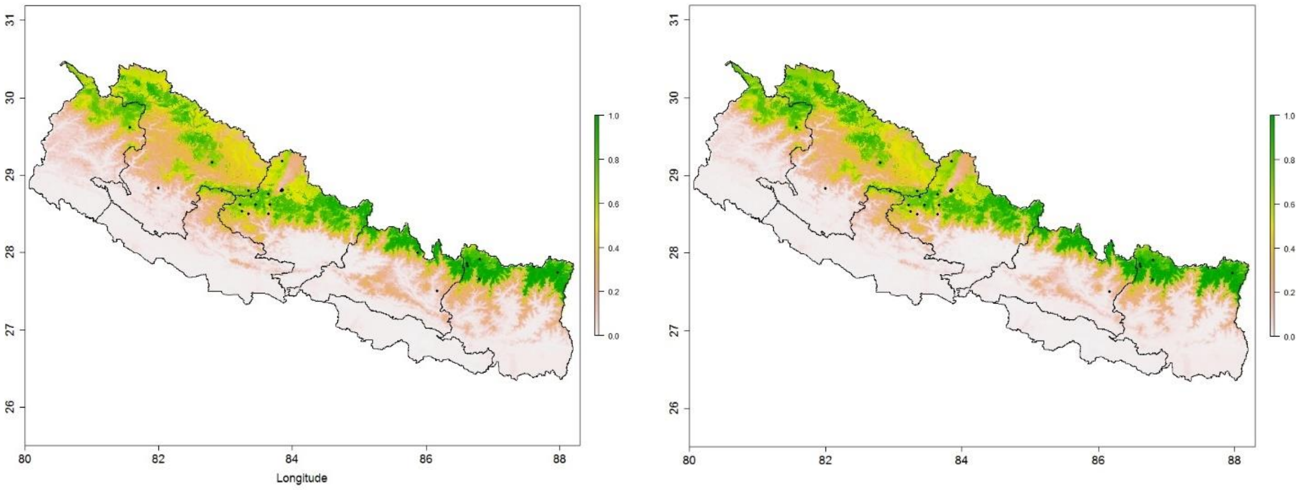


a. Habitat suitability under current climate



b. Habitat suitability in 2050 (RCP 6)

c. Habitat suitability in 2070 (RCP 6)



d. Habitat suitability in 2050 (RCP 8.5)

e. Habitat suitability in 2070 (RCP 8.5)

Appendix 16: Potential suitable area (km^2) for *Swertia alata* in different districts and provinces of Nepal

a. Potential suitable area in different districts of Nepal

District	Suitable Area in Current Climate	RCP 6		RCP 8.5	
		Suitable Area in 2050	Suitable Area in 2070	Suitable Area in 2050	Suitable Area in 2070
ACHHAM	693.7	0.75	0	0	0
ARGHAKHANCHI	162.44	0	0	0	0
BAGLUNG	1312.94	21.05	8.27	10.52	1.5
BAITADI	682.79	2.98	0	0	0
BAJHANG	1140.27	13.37	10.4	10.4	2.97
BAJURA	1404.03	111.57	81.08	86.28	41.66
BANKE	3.77	0	0	0	0
BARA	109.66	0	0	0	0
BARDIYA	0	0	0	0	0
BHAKTAPUR	121.21	36.36	15.91	16.66	4.54
BHOJPUR	774.23	0.76	0	0	0
CHITAWAN	127.96	0	0	0	0
DADELDHURA	328.22	0.75	0	0	0
DAILEKH	817.3	0	0	0	0
DANG	95.78	0	0	0	0
DARCHULA	917.18	102.25	76.32	81.5	42.99
DHADING	1015.84	2.27	1.51	2.27	1.51
DHANKUTA	252.17	6.1	2.29	2.29	0
DHANUSHA	61.11	0	0	0	0
DOLAKHA	1789.99	32.52	17.4	19.66	2.27
DOLPA	1122.27	26.92	18.69	19.44	14.95
DOTI	586.86	0	0	0	0
GORKHA	1767.96	27.81	16.53	18.04	8.27
GULMI	558.41	0	0	0	0
HUMLA	1362.47	318.85	213.5	231.29	131.9
ILAM	366.67	0	0	0	0
JAJARKOT	1374.87	20.94	9.72	12.71	3.74
JHAPA	90.97	0	0	0	0
JUMLA	1878.41	180.59	97.75	109.69	49.24
KABHREPALANCHOK	858.44	18.19	7.58	9.09	1.52
KAILALI	40.45	0	0	0	0
KALIKOT	1489.02	111.21	83.58	86.57	44.78
KANCHANPUR	17.95	0	0	0	0
KAPILBASTU	22.76	0	0	0	0
KASKI	592.51	0.75	0.75	0	0
KATHMANDU	402.06	188.53	157.49	162.03	108.28
KHOTANG	661.62	0	0	0	0
LALITPUR	273.74	25.76	7.58	6.82	3.03
LAMJUNG	576.01	0	0	0	0
MAHOTTARI	29.04	0	0	0	0
MAKAWANPUR	584.56	0	0	0	0
MANANG	645.18	1.5	3.01	3.01	3.76
MORANG	186.73	0	0	0	0
MUGU	1346.02	178.59	107.9	117.57	71.44
MUSTANG	1420.76	36.74	28.49	30.74	23.99
MYAGDI	1407.26	1.5	1.5	1.5	0.75
NAWALPUR	102.2	0	0	0	0
PARASI	0	0	0	0	0
NUWAKOT	757.29	0	0	0	0
OKHALDHUNGA	591.74	5.31	3.04	3.04	0

PALPA	431.18	3.78	0.76	0.76	0
PANCHTHAR	738.27	3.05	0	0	0
PARBAT	378.38	0	0	0	0
PARSA	77.7	0	0	0	0
PYUTHAN	303.84	0	0	0	0
RAMECHHAP	1024.63	3.03	2.28	2.28	0
RASUWA	1049.06	19.6	10.56	10.56	3.02
RAUTAHAT	25.96	0	0	0	0
ROLPA	1172.01	0	0	0	0
EASTERN RUKUM	1163.54	20.27	10.51	11.26	4.5
WESTERN RUKUM	801.1	8.24	2.25	3.75	2.25
RUPANDEHI	104.61	0	0	0	0
SALYAN	868.15	0	0	0	0
SANKHUWASABHA	2506.21	5.31	2.27	3.79	2.27
SAPTARI	165.2	0	0	0	0
SARLAHI	12.97	0	0	0	0
SINDHULI	229.63	0	0	0	0
SINDHUPALCHOK	2128.88	43.87	24.96	26.48	5.29
SIRAHA	45.83	0	0	0	0
SOLUKHUMBU	2061.43	59.08	31.03	34.82	13.62
SUNSARI	332.46	5.34	0	0	0
SURKHET	582.68	0	0	0	0
SYANGJA	339.84	0	0	0	0
TANAHU	228.31	0	0	0	0
TAPLEJUNG	2236.65	3.79	0	0	0
TERHATHUM	328.72	0	0	0	0
UDAYAPUR	299.72	0	0	0	0
Total	**52561.78**	**1649.29**	**1054.89**	**1134.82**	**594.04**

b. Potential suitable area in different provinces of Nepal

Province	Suitable Area in Current Climate	RCP 6		RCP 8.5	
		Suitable Area in 2050	Suitable Area in 2070	Suitable Area in 2050	Suitable Area in 2070
BAGMATI	10363.27	370.14	245.26	255.85	129.46
GANDAKI	19545.48	934.7	591.94	644.83	356.57
KARNALI	30717.91	845.34	533.39	581.03	318.3
LUMBINI	4018.34	24.05	11.26	12.01	4.5
MADHESH	527.49	0	0	0	0
PROVINCE 1	11427.58	88.74	38.62	43.93	15.89
SUDUR PASCHIM	5811.46	231.66	167.8	178.18	87.62

Appendix 17: Potential suitable area (km^2) for *Swertia angustifolia* in different districts and provinces of Nepal

a. Potential suitable area in different districts of Nepal

District	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
ACHHAM	252.63	0	0	0	0
ARGHAKHANCHI	216.85	0	0	0	0
BAGLUNG	1043.06	0	0	0	0
BAITADI	237.56	0	0	0	0
BAJHANG	299.02	0	0	0	0
BAJURA	582.22	0	0	0	0
BANKE	0	0	0	0	0
BARA	4.57	0	0	0	0
BARDIYA	0	0	0	0	0
BHAKTAPUR	117.42	0	0	0	0
BHOJPUR	532.34	0	0	0	0
CHITAWAN	46.93	0	0	0	0
DADELDHURA	122.34	0	0	0	0
DAILEKH	388.08	0	0	0	0
DANG	61.83	0	0	0	0
DARCHULA	281.15	0	0	0	0
DHADING	580.54	0	0	0	0
DHANKUTA	133.28	0	0	0	0
DHANUSHA	10.69	0	0	0	0
DOLAKHA	1332.88	0	0	0	0
DOLPA	220.7	0	0	0	0
DOTI	263.69	0	0	0	0
GORKHA	1267.88	0	0	0	0
GULMI	513.84	0	0	0	0
HUMLA	503.21	0	0	0	0
ILAM	250	0	0	0	0
JAJARKOT	657.16	0	0	0	0
JHAPA	0	0	0	0	0
JUMLA	544.78	0	0	0	0
KABHREPALANCHOK	514.96	0	0	0	0
KAILALI	9.73	0	0	0	0
KALIKOT	611.36	0	0	0	0
KANCHANPUR	0	0	0	0	0
KAPILBASTU	2.28	0	0	0	0
KASKI	701.02	0	0	0	0
KATHMANDU	388.43	0	0	0	0
KHOTANG	503.42	0	0	0	0
LALITPUR	282.09	0	0	0	0
LAMJUNG	688.3	0	0	0	0
MAHOTTARI	0	0	0	0	0
MAKAWANPUR	531.39	0	0	0	0
MANANG	380.87	0	0	0	0
MORANG	22.95	0	0	0	0
MUGU	424.89	0	0	0	0
MUSTANG	199.62	0	0	0	0
MYAGDI	1111.93	0	0	0	0
NAWALPUR	64.33	0	0	0	0
PARASI	0	0	0	0	0
NUWAKOT	536.56	0	0	0	0
OKHALDHUNGA	477.78	0	0	0	0

PALPA	357.07	0	0	0	0
PANCHTHAR	417.83	0	0	0	0
PARBAT	333.89	0	0	0	0
PARSA	22.85	0	0	0	0
PYUTHAN	303.04	0	0	0	0
RAMECHHAP	663.5	0	0	0	0
RASUWA	721.05	0	0	0	0
RAUTAHAT	0	0	0	0	0
ROLPA	1190.89	0	0	0	0
EASTERN RUKUM	611.2	0	0	0	0
WESTERN RUKUM	435.22	0	0	0	0
RUPANDEHI	0	0	0	0	0
SALYAN	635.09	0	0	0	0
SANKHUWASABHA	1730.51	0	0	0	0
SAPTARI	0.77	0	0	0	0
SARLAHI	0	0	0	0	0
SINDHULI	77.58	0	0	0	0
SINDHUPALCHOK	1691.16	0	0	0	0
SIRAHA	0	0	0	0	0
SOLUKHUMBU	1528.24	0	0	0	0
SUNSARI	11.47	0	0	0	0
SURKHET	297.44	0	0	0	0
SYANGJA	201.53	0	0	0	0
TANAHU	37.05	0	0	0	0
TAPLEJUNG	1556.14	0	0	0	0
TERHATHUM	232.05	0	0	0	0
UDAYAPUR	79.3	0	0	0	0
Total	**31051.41**	**0**	**0**	**0**	**0**

b. Potential suitable area in different provinces of Nepal

Province	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
BAGMATI	7484.49	0	0	0	0
GANDAKI	10112.31	0	0	0	0
KARNALI	18231.89	0	0	0	0
LUMBINI	3256.99	0	0	0	0
MADHESH	38.88	0	0	0	0
PROVINCE 1	7475.31	0	0	0	0
SUDUR PASCHIM	2048.34	0	0	0	0

Appendix 18: Potential suitable area (km²) for *Swertia ciliata* in different districts and provinces of Nepal

a. Potential suitable area in different districts of Nepal

District	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
ACHHAM	177.77	10.45	1.49	1.49	0
ARGHAKHANCHI	0	0	0	0	0
BAGLUNG	835.12	227.73	144.28	138.27	84.15
BAITADI	254.63	1.49	0	0	0
BAJHANG	1427.3	823.12	583.96	524.58	316
BAJURA	1372.08	680.98	489.78	496.46	296.44
BANKE	0	0	0	0	0
BARA	0	0	0	0	0
BARDIYA	0	0	0	0	0
BHAKTAPUR	40.9	3.79	0	0	0
BHOJPUR	142.12	0	0	0	0
CHITAWAN	0	0	0	0	0
DADELDHURA	91.01	0	0	0	0
DAILEKH	195.46	15.71	3.74	4.49	1.5
DANG	0.75	0	0	0	0
DARCHULA	1194	986.56	772.32	747.84	425.64
DHADING	282.01	5.28	4.53	4.53	2.27
DHANKUTA	12.18	0	0	0	0
DHANUSHA	0	0	0	0	0
DOLAKHA	1519.21	145.91	88.44	94.49	30.99
DOLPA	2044.35	3621.72	2744.6	2769.38	1987.64
DOTI	255.23	6.71	0	0	0
GORKHA	1040.18	184.89	127.74	133.01	113.43
GULMI	25.65	0	0	0	0
HUMLA	1578.66	2567.55	1861.16	1839.56	1301.66
ILAM	5.33	0	0	0	0
JAJARKOT	899.88	308.2	225.89	223.65	154.06
JHAPA	0	0	0	0	0
JUMLA	2174.86	1627.65	1016.55	1036.72	567.31
KABHREPALANCHOK	91	0.76	0	0	0
KAILALI	0	0	0	0	0
KALIKOT	1267.34	542.86	330.04	335.26	116.47
KANCHANPUR	0	0	0	0	0
KAPILBASTU	0	0	0	0	0
KASKI	69.22	0	0	0	0
KATHMANDU	228.66	73.44	6.06	6.06	0.76
KHOTANG	161.94	0.76	0	0	0
LALITPUR	39.41	0.76	0	0	0
LAMJUNG	196.39	0	0	0	0
MAHOTTARI	0	0	0	0	0
MAKAWANPUR	117.48	0	0	0	0
MANANG	705.93	246.99	284.53	286.03	291.26
MORANG	0	0	0	0	0
MUGU	1343.86	1446.3	1081.8	1032.69	719.45
MUSTANG	1556.28	1526.51	1469.64	1473.39	1392.41
MYAGDI	928.16	45.08	27.79	24.79	17.27
NAWALPUR	0	0	0	0	0
PARASI	0	0	0	0	0
NUWAKOT	141.26	0	0	0	0
OKHALDHUNGA	310.59	13.66	6.07	8.35	2.28

PALPA	0.76	0	0	0	0
PANCHTHAR	133.93	6.09	0	0	0
PARBAT	32.37	0	0	0	0
PARSA	0	0	0	0	0
PYUTHAN	67.04	0.75	0	0	0
RAMECHHAP	650.29	13.65	3.79	3.79	0
RASUWA	896.49	166.64	87.47	92.75	43.74
RAUTAHAT	0	0	0	0	0
ROLPA	540.17	25.57	4.51	3.76	0
EASTERN RUKUM	1329.99	436.04	243.9	255.9	116.31
WESTERN RUKUM	557.8	176.05	106.36	107.86	62.17
RUPANDEHI	0	0	0	0	0
SALYAN	75.21	0	0	0	0
SANKHUWASABHA	1004.25	29.52	4.54	9.08	1.51
SAPTARI	0	0	0	0	0
SARLAHI	0	0	0	0	0
SINDHULI	11.41	0	0	0	0
SINDHUPALCHOK	1216.42	77.89	36.3	37.06	7.57
SIRAHA	0	0	0	0	0
SOLUKHUMBU	2031.78	140.92	71.17	85.57	41.62
SUNSARI	0	0	0	0	0
SURKHET	51.81	0	0	0	0
SYANGJA	0	0	0	0	0
TANAHU	0.76	0	0	0	0
TAPLEJUNG	711.95	66.73	3.03	6.06	0
TERHATHUM	25.1	0	0	0	0
UDAYAPUR	3.05	0	0	0	0
Total	**32066.78**	**16254.71**	**11831.48**	**11782.87**	**8093.91**

b. Potential suitable area in different provinces of Nepal

Province	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
BAGMATI	5234.54	488.12	226.59	238.68	85.33
GANDAKI	15478.43	12537.24	9424.12	9405.1	6808.78
KARNALI	20788.18	10306.04	7370.14	7349.61	4910.26
LUMBINI	1964.36	462.36	248.41	259.66	116.31
MADHESH	0	0	0	0	0
PROVINCE 1	4542.22	257.68	84.81	109.06	45.41
SUDUR PASCHIM	4772.02	2509.31	1847.55	1770.37	1038.08

Appendix 19: Potential suitable area (km^2) for *Swertia dilatata* in different districts and provinces of Nepal

a. Potential suitable area in different districts of Nepal

District	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
ACHHAM	0	0	0	0	0
ARGHAKHANCHI	3.02	0	0	0	0
BAGLUNG	355.47	0	0	0	0
BAITADI	0	0	0	0	0
BAJHANG	35.66	0	0	0	0
BAJURA	29.76	0	0	0	0
BANKE	0	0	0	0	0
BARA	0	0	0	0	0
BARDIYA	0	0	0	0	0
BHAKTAPUR	0.76	0	0	0	0
BHOJPUR	602.29	0	0	0	0
CHITAWAN	0	0	0	0	0
DADELDHURA	0	0	0	0	0
DAILEKH	0	0	0	0	0
DANG	0	0	0	0	0
DARCHULA	33.38	0	0	0	0
DHADING	397.47	0	0	0	0
DHANKUTA	159.97	0	0	0	0
DHANUSHA	0	0	0	0	0
DOLAKHA	962.49	0	0	0	0
DOLPA	3	0	0	0	0
DOTI	0.75	0	0	0	0
GORKHA	965.24	0	0	0	0
GULMI	28.67	0	0	0	0
HUMLA	2.22	0	0	0	0
ILAM	741.08	0	0	0	0
JAJARKOT	19.45	0	0	0	0
JHAPA	0	0	0	0	0
JUMLA	19.42	0	0	0	0
KABHREPALANCHOK	208.67	0	0	0	0
KAILALI	0	0	0	0	0
KALIKOT	13.43	0	0	0	0
KANCHANPUR	0	0	0	0	0
KAPILBASTU	0	0	0	0	0
KASKI	237.8	0	0	0	0
KATHMANDU	31.05	0	0	0	0
KHOTANG	590.85	0	0	0	0
LALITPUR	87.99	0	0	0	0
LAMJUNG	511.95	0	0	0	0
MAHOTTARI	0	0	0	0	0
MAKAWANPUR	252.41	0	0	0	0
MANANG	287.05	0	0	0	0
MORANG	80.9	0	0	0	0
MUGU	2.23	0	0	0	0
MUSTANG	115.6	0	0	0	0
MYAGDI	594.41	0	0	0	0
NAWALPUR	3.78	0	0	0	0
PARASI	0	0	0	0	0
NUWAKOT	188.82	0	0	0	0
OKHALDHUNGA	397.98	0	0	0	0

PALPA	7.57	0	0	0	0
PANCHTHAR	662.27	0	0	0	0
PARBAT	27.86	0	0	0	0
PARSA	0	0	0	0	0
PYUTHAN	48.21	0	0	0	0
RAMECHHAP	516.18	0	0	0	0
RASUWA	485.71	0	0	0	0
RAUTAHAT	0	0	0	0	0
ROLPA	54.18	0	0	0	0
EASTERN RUKUM	77.27	0	0	0	0
WESTERN RUKUM	6	0	0	0	0
RUPANDEHI	0	0	0	0	0
SALYAN	0	0	0	0	0
SANKHUWASABHA	1815.59	0	0	0	0
SAPTARI	0	0	0	0	0
SARLAHI	0	0	0	0	0
SINDHULI	41.86	0	0	0	0
SINDHUPALCHOK	981.36	0	0	0	0
SIRAHA	0	0	0	0	0
SOLUKHUMBU	1586.17	0	0	0	0
SUNSARI	5.34	0	0	0	0
SURKHET	0	0	0	0	0
SYANGJA	3.77	0	0	0	0
TANAHU	0	0	0	0	0
TAPLEJUNG	1524.8	0	0	0	0
TERHATHUM	308.9	0	0	0	0
UDAYAPUR	54.11	0	0	0	0
Total	**16172.17**	**0**	**0**	**0**	**0**

b. Potential suitable area in different provinces of Nepal

Province	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
BAGMATI	4154.77	0	0	0	0
GANDAKI	3168.69	0	0	0	0
KARNALI	7323.46	0	0	0	0
LUMBINI	218.92	0	0	0	0
MADHESH	0	0	0	0	0
PROVINCE 1	8530.24	0	0	0	0
SUDUR PASCHIM	99.55	0	0	0	0

Appendix 20: Potential suitable area (km^2) for *Swertia multicaulis* in different districts and provinces of Nepal

a. Potential suitable area in different districts of Nepal

District	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
ACHHAM	0	0	0	0	0
ARGHAKHANCHI	0	0	0	0	0
BAGLUNG	15.03	0	0	0	0
BAITADI	0	0	0	0	0
BAJHANG	0	103.08	63.78	0	0
BAJURA	0.75	11.13	2.22	0	0
BANKE	0	0	0	0	0
BARA	0	0	0	0	0
BARDIYA	0	0	0	0	0
BHAKTAPUR	0	0	0	0	0
BHOJPUR	1.52	0	0	0	0
CHITAWAN	0	0	0	0	0
DADELDHURA	0	0	0	0	0
DAILEKH	0	0	0	0	0
DANG	0	0	0	0	0
DARCHULA	0	84.25	66.5	0	0
DHADING	51.23	0	0	0	0
DHANKUTA	0	0	0	0	0
DHANUSHA	0	0	0	0	0
DOLAKHA	408.86	0	0	0	0
DOLPA	14.23	2.25	2.25	0	0
DOTI	0	0	0	0	0
GORKHA	191.61	12.78	9.77	0	0
GULMI	0	0	0	0	0
HUMLA	0	125.17	54.77	0	0
ILAM	0	0	0	0	0
JAJARKOT	0	0	0	0	0
JHAPA	0	0	0	0	0
JUMLA	0	2.98	0.74	0	0
KABHREPALANCHOK	0	0	0	0	0
KAILALI	0	0	0	0	0
KALIKOT	1.49	0	0	0	0
KANCHANPUR	0	0	0	0	0
KAPILBASTU	0	0	0	0	0
KASKI	81.98	33.83	24.05	0	0
KATHMANDU	0	0	0	0	0
KHOTANG	0	0	0	0	0
LALITPUR	0	0	0	0	0
LAMJUNG	55.67	0	0	0	0
MAHOTTARI	0	0	0	0	0
MAKAWANPUR	0	0	0	0	0
MANANG	185.37	27.05	11.26	0	0
MORANG	0	0	0	0	0
MUGU	0	39.37	0	0	0
MUSTANG	16.49	6.54	5.25	0	0
MYAGDI	152.47	38.28	29.27	0	0
NAWALPUR	0	0	0	0	0
PARASI	0	0	0	0	0
NUWAKOT	17.36	0	0	0	0
OKHALDHUNGA	0	0	0	0	0

PALPA	0	0	0	0	0
PANCHTHAR	0	0	0	0	0
PARBAT	0	0	0	0	0
PARSA	0	0	0	0	0
PYUTHAN	0	0	0	0	0
RAMECHHAP	153.68	0	0	0	0
RASUWA	184.68	0	0.75	0	0
RAUTAHAT	0	0	0	0	0
ROLPA	0	0	0	0	0
EASTERN RUKUM	6.75	3	0	0	0
WESTERN RUKUM	0	0	0	0	0
RUPANDEHI	0	0	0	0	0
SALYAN	0	0	0	0	0
SANKHUWASABHA	582.33	0	0	0	0
SAPTARI	0	0	0	0	0
SARLAHI	0	0	0	0	0
SINDHULI	0	0	0	0	0
SINDHUPALCHOK	298.87	0	0	0	0
SIRAHA	0	0	0	0	0
SOLUKHUMBU	1069.16	1.51	0	0	0
SUNSARI	0	0	0	0	0
SURKHET	0	0	0	0	0
SYANGJA	0	0	0	0	0
TANAHU	0	0	0	0	0
TAPLEJUNG	379.54	14.41	18.95	0	0
TERHATHUM	0	0	0	0	0
UDAYAPUR	0	0	0	0	0
Total	**3869.07**	**505.63**	**289.58**	**0**	**0**

b. Potential suitable area in different provinces of Nepal

Province	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
BAGMATI	1114.67	0	0.75	0	0
GANDAKI	714.35	288.25	137.37	0	0
KARNALI	1829.02	169.78	57.76	0	0
LUMBINI	6.75	3	0	0	0
MADHESH	0	0	0	0	0
PROVINCE 1	2032.54	15.92	18.95	0	0
SUDUR PASCHIM	0.75	198.46	132.5	0	0

Appendix 21: Potential suitable area (km^2) for *Swertia nervosa* in different districts and provinces of Nepal

a. Potential suitable area in different districts of Nepal

District	Suitable Area in Current Climate	RCP 6		RCP 8.5	
		Suitable Area in 2050	Suitable Area in 2070	Suitable Area in 2050	Suitable Area in 2070
ACHHAM	253.07	0	0	0	0
ARGHAKHANCHI	846.58	0	0	0	0
BAGLUNG	1605.1	0	0	0	0
BAITADI	186.14	0	0	0	0
BAJHANG	977.24	0	0	0	0
BAJURA	784.75	0	0	0	0
BANKE	4.53	0	0	0	0
BARA	68.41	0	0	0	0
BARDIYA	51.87	0	0	0	0
BHAKTAPUR	20.45	0	0	0	0
BHOJPUR	835.89	0	0	0	0
CHITAWAN	282.62	0	0	0	0
DADELDHURA	478.65	0	0	0	0
DAILEKH	464.28	0	0	0	0
DANG	754.07	0	0	0	0
DARCHULA	578.06	0	0	0	0
DHADING	674.01	0	0	0	0
DHANKUTA	311.69	0	0	0	0
DHANUSHA	133.37	0	0	0	0
DOLAKHA	1534.62	0	0	0	0
DOLPA	219.81	0	0	0	0
DOTI	930.18	0	0	0	0
GORKHA	1581.82	0	0	0	0
GULMI	863.18	0	0	0	0
HUMLA	217.48	0	0	0	0
ILAM	91.47	0	0	0	0
JAJARKOT	977.91	0	0	0	0
JHAPA	1.53	0	0	0	0
JUMLA	585.08	0	0	0	0
KABHREPALANCHOK	588.82	0	0	0	0
KAILALI	316.76	0	0	0	0
KALIKOT	554.78	0	0	0	0
KANCHANPUR	33.66	0	0	0	0
KAPILBASTU	76.45	0	0	0	0
KASKI	924.76	0	0	0	0
KATHMANDU	149.16	0	0	0	0
KHOTANG	811.53	0	0	0	0
LALITPUR	311.02	0	0	0	0
LAMJUNG	1041.72	0	0	0	0
MAHOTTARI	163.74	0	0	0	0
MAKAWANPUR	1163.55	0	0	0	0
MANANG	533.34	0	0	0	0
MORANG	9.17	0	0	0	0
MUGU	225.49	0	0	0	0
MUSTANG	183.15	0	0	0	0
MYAGDI	1314.13	0	0	0	0
NAWALPUR	352.08	0	0	0	0
PARASI	77.31	0	0	0	0
NUWAKOT	466.96	0	0	0	0
OKHALDHUNGA	890.53	0	0	0	0

PALPA	1060.07	0	0	0	0
PANCHTHAR	470.44	0	0	0	0
PARBAT	430.4	0	0	0	0
PARSA	113.92	0	0	0	0
PYUTHAN	932.3	0	0	0	0
RAMECHHAP	985.15	0	0	0	0
RASUWA	966.1	0	0	0	0
RAUTAHAT	53.26	0	0	0	0
ROLPA	1696.9	0	0	0	0
EASTERN RUKUM	951.19	0	0	0	0
WESTERN RUKUM	392.31	0	0	0	0
RUPANDEHI	108.28	0	0	0	0
SALYAN	727.86	0	0	0	0
SANKHUWASABHA	1911.77	0	0	0	0
SAPTARI	0	0	0	0	0
SARLAHI	131.7	0	0	0	0
SINDHULI	1133.87	0	0	0	0
SINDHUPALCHOK	1596.83	0	0	0	0
SIRAHA	84.7	0	0	0	0
SOLUKHUMBU	1874.37	0	0	0	0
SUNSARI	3.82	0	0	0	0
SURKHET	302.76	0	0	0	0
SYANGJA	471.72	0	0	0	0
TANAHU	59.75	0	0	0	0
TAPLEJUNG	1801.29	0	0	0	0
TERHATHUM	343.95	0	0	0	0
UDAYAPUR	462.8	0	0	0	0
Total	**45569.49**	**0**	**0**	**0**	**0**

b. Potential suitable area in different provinces of Nepal

Province	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
BAGMATI	9873.15	0	0	0	0
GANDAKI	12437.88	0	0	0	0
KARNALI	23038.9	0	0	0	0
LUMBINI	7422.73	0	0	0	0
MADHESH	749.08	0	0	0	0
PROVINCE 1	9820.25	0	0	0	0
SUDUR PASCHIM	4538.53	0	0	0	0

Appendix 22: Potential suitable area (km²) for *Swertia racemosa* in different districts and provinces of Nepal

a. Potential suitable area in different districts of Nepal

District	Suitable Area in Current Climate	RCP 6		RCP 8.5	
		Suitable Area in 2050	Suitable Area in 2070	Suitable Area in 2050	Suitable Area in 2070
ACHHAM	10.44	0	0	0	0
ARGHAKHANCHI	4.54	0	0	0	0
BAGLUNG	766.15	193.18	154.82	151.06	91.68
BAITADI	0.74	0	0	0	0
BAJHANG	1463.39	1280.83	1291.14	1250.35	1241.32
BAJURA	877.27	653.54	648.3	646.08	591.76
BANKE	0	0	0	0	0
BARA	0	0	0	0	0
BARDIYA	0	0	0	0	0
BHAKTAPUR	0	0	0	0	0
BHOJPUR	88.15	4.56	3.8	3.8	3.8
CHITAWAN	0	0	0	0	0
DADELDHURA	0	0	0	0	0
DAILEKH	24.7	0	0	0	0
DANG	0	0	0	0	0
DARCHULA	1460.66	1185.82	1175.33	1093.12	1073.73
DHADING	221.55	257.73	255.47	257.73	246.43
DHANKUTA	3.04	0	0	0	0
DHANUSHA	0	0	0	0	0
DOLAKHA	980.65	864.79	867.81	865.55	848.9
DOLPA	4132.63	1710.42	2993.2	3009.87	4157.51
DOTI	15.68	0	0	0	0
GORKHA	1738.13	1931.44	1929.18	1934.45	1890.76
GULMI	55.84	0	0	0	0
HUMLA	2776.19	3885.25	4465.38	4326.9	4605.21
ILAM	1.52	3.05	1.52	1.52	0.76
JAJARKOT	350.15	202.69	190.72	187.72	142.1
JHAPA	0	0	0	0	0
JUMLA	622.66	403.01	398.48	391.79	349.91
KABHREPALANCHOK	10.63	0	0	0	0
KAILALI	0	0	0	0	0
KALIKOT	180.65	15.67	11.94	12.69	5.22
KANCHANPUR	0	0	0	0	0
KAPILBASTU	0	0	0	0	0
KASKI	719.02	713.54	681.19	688.71	635.29
KATHMANDU	4.54	0	0	0	0
KHOTANG	53.2	4.56	4.56	3.04	2.28
LALITPUR	3.03	0	0	0	0
LAMJUNG	442.52	465.83	453.03	461.31	428.19
MAHOTTARI	0	0	0	0	0
MAKAWANPUR	3.79	0	0	0	0
MANANG	1862.09	2112.79	2208.05	2211.8	2205.01
MORANG	0	0	0	0	0
MUGU	1096.45	1198.73	1666.83	1554.63	1696.51
MUSTANG	1639.98	1632.8	2072.82	2077.29	2083.24
MYAGDI	1513.73	1303.66	1255.53	1242.76	1132.28
NAWALPUR	0.76	0	0	0	0
PARASI	0	0	0	0	0
NUWAKOT	58.89	59.65	58.9	58.9	54.36
OKHALDHUNGA	112.38	2.28	2.28	2.28	1.52

PALPA	5.3	0	0	0	0
PANCHTHAR	40.28	49.41	44.85	43.32	41.04
PARBAT	58.76	13.55	6.77	8.28	1.51
PARSA	0	0	0	0	0
PYUTHAN	96.4	2.26	0.75	0.75	0
RAMECHHAP	362.03	263.5	259.71	256.68	255.17
RASUWA	841.22	966.34	959.54	963.32	943.7
RAUTAHAT	0	0	0	0	0
ROLPA	207.65	2.26	0	1.5	0
EASTERN RUKUM	595.75	344.97	331.46	328.47	277.44
WESTERN RUKUM	200.83	80.91	78.66	78.66	65.93
RUPANDEHI	0	0	0	0	0
SALYAN	0	0	0	0	0
SANKHUWASABHA	1330.61	1322.7	1290.13	1296.18	1259.06
SAPTARI	0	0	0	0	0
SARLAHI	0	0	0	0	0
SINDHULI	0	0	0	0	0
SINDHUPALCHOK	770.81	751.85	763.94	762.43	729.18
SIRAHA	0	0	0	0	0
SOLUKHUMBU	2344.36	2113.03	2100.13	2100.13	2082.69
SUNSARI	0	0	0	0	0
SURKHET	0	0	0	0	0
SYANGJA	19.61	0	0	0	0
TANAHU	0	0	0	0	0
TAPLEJUNG	1825.65	2207.31	2152.68	2154.2	2120.81
TERHATHUM	8.37	0	0	0	0
UDAYAPUR	0	0	0	0	0
Total	**32003.39**	**28203.88**	**30778.93**	**30427.26**	**31264.31**

b. Potential suitable area in different provinces of Nepal

Province	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
BAGMATI	3257.16	3163.86	3165.38	3164.6	3077.75
GANDAKI	18145.01	15863.46	18566.62	18337.93	19490.35
KARNALI	21402.16	7496.68	9805.23	9562.27	11022.39
LUMBINI	965.48	349.49	332.22	330.72	277.44
MADHESH	0	0	0	0	0
PROVINCE 1	5807.57	5706.88	5599.94	5604.46	5511.96
SUDUR PASCHIM	3828.18	3120.19	3114.78	2989.54	2906.81

Appendix 23: Potential suitable area (km^2) in protected areas for *Swertia alata*

Name	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
Annapurna Conservation Area	2767.12	38.24	31.49	33.74	27.74
Gaurishankar Conservation Area	1975.42	32.49	18.89	21.16	4.53
Langtang National Park	1071.34	14.32	9.05	9.05	3.02
Kanchanjunga Conservation Area	917.96	2.28	0	0	0
Dhorpatan Hunting Reserve	806.55	30.05	14.28	16.53	3.01
Manaslu Conservation Area	778.85	26.31	16.53	18.04	8.27
Api Nampa Conservation Area	728.51	90.41	72.62	73.36	44.47
Makalu Barun National Park	658.29	0	0	0	0
Sagarmatha National Park	395.46	31.02	26.48	27.99	13.62
Shey Phoksundo National Park	171.53	44.66	22.33	26.79	22.33
Shivapuri Nagarjun National Park	109.73	27.25	21.19	22.71	9.84
Rara National Park	108.71	1.49	0	0	0
Khaptad National Park	98.39	0	0	0	0
Koshi Tappu Wildlife Reserve	42.05	0	0	0	0
Banke National Park	0	0	0	0	0
Bardia National Park	0	0	0	0	0
Chitawan National Park	0	0	0	0	0
Parsa National Park	0	0	0	0	0
Suklaphanta National Park	0	0	0	0	0
Krishnashaar Conservation Area	0	0	0	0	0
Total	**4816.03**	**253.47**	**173.43**	**185.42**	**101.54**

Appendix 24: Potential suitable area (km^2) in protected areas for *Swertia angustifolia*

Name	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
Gaurishankar Conservation Area	1523.14	0	0	0	0
Annapurna Conservation Area	1406.13	0	0	0	0
Langtang National Park	691.89	0	0	0	0
Kanchanjunga Conservation Area	617.73	0	0	0	0
Manaslu Conservation Area	553.33	0	0	0	0
Dhorpatan Hunting Reserve	280.15	0	0	0	0
Makalu Barun National Park	262.89	0	0	0	0
Api Nampa Conservation Area	245.5	0	0	0	0
Sagarmatha National Park	237.46	0	0	0	0
Shivapuri Nagarjun National Park	106.7	0	0	0	0
Khaptad National Park	14.16	0	0	0	0
Rara National Park	12.66	0	0	0	0
Shey Phoksundo National Park	7.46	0	0	0	0
Koshi Tappu Wildlife Reserve	0.76	0	0	0	0
Banke National Park	0	0	0	0	0
Bardia National Park	0	0	0	0	0
Chitawan National Park	0	0	0	0	0
Parsa National Park	0	0	0	0	0
Suklaphanta National Park	0	0	0	0	0
Krishnashaar Conservation Area	0	0	0	0	0
Total	**5959.98**	**0**	**0**	**0**	**0**

Appendix 25: Potential suitable area (km^2) in protected areas for *Swertia ciliata*

Name	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
Annapurna Conservation Area	2414.1	1775.77	1753.42	1757.92	1683.68
Gaurishankar Conservation Area	1957.95	176.15	97.51	103.55	32.5
Langtang National Park	1138.39	125.18	68.62	71.64	39.97
Api Nampa Conservation Area	1067.19	831.35	637.84	615.58	347.32
Dhorpatan Hunting Reserve	971.65	474.59	326.64	317.63	196.73
Manaslu Conservation Area	745.69	178.12	125.49	130.75	110.43
Sagarmatha National Park	580.64	55.99	49.93	52.2	37.07
Shey Phoksundo National Park	444.52	1749.41	1321.28	1259.48	928.24
Kanchanjunga Conservation Area	438.67	52.31	3.03	5.31	0
Makalu Barun National Park	276.49	0	0	0	0
Khaptad National Park	138.64	9.69	0	0	0
Rara National Park	107.96	53.61	13.4	14.15	5.96
Shivapuri Nagarjun National Park	58.27	5.3	3.03	3.03	1.51
Banke National Park	0	0	0	0	0
Bardia National Park	0	0	0	0	0
Chitawan National Park	0	0	0	0	0
Koshi Tappu Wildlife Reserve	0	0	0	0	0
Parsa National Park	0	0	0	0	0
Suklaphanta National Park	0	0	0	0	0
Krishnashaar Conservation Area	0	0	0	0	0
Total	**10340.16**	**5487.47**	**4400.19**	**4331.24**	**3383.41**

Appendix 26: Potential suitable area (km^2) in protected areas for *Swertia dilatata*

Name	Suitable Area in Current Climate	RCP 6		RCP 8.5	
		Suitable Area in 2050	Suitable Area in 2070	Suitable Area in 2050	Suitable Area in 2070
Gaurishankar Conservation Area	1431.85	0	0	0	0
Annapurna Conservation Area	805.22	0	0	0	0
Langtang National Park	617.34	0	0	0	0
Kanchanjunga Conservation Area	467.12	0	0	0	0
Manaslu Conservation Area	397.81	0	0	0	0
Makalu Barun National Park	346.26	0	0	0	0
Dhorpatan Hunting Reserve	153.97	0	0	0	0
Sagarmatha National Park	111.2	0	0	0	0
Api Nampa Conservation Area	33.38	0	0	0	0
Shivapuri Nagarjun National Park	23.46	0	0	0	0
Banke National Park	0	0	0	0	0
Bardia National Park	0	0	0	0	0
Chitawan National Park	0	0	0	0	0
Khaptad National Park	0	0	0	0	0
Koshi Tappu Wildlife Reserve	0	0	0	0	0
Parsa National Park	0	0	0	0	0
Rara National Park	0	0	0	0	0
Shey Phoksundo National Park	0	0	0	0	0
Suklaphanta National Park	0	0	0	0	0
Krishnashaar Conservation Area	0	0	0	0	0
Total	**4387.61**	**0**	**0**	**0**	**0**

Appendix 27: Potential suitable area (km^2) in protected areas for *Swertia multicaulis*

Name	Suitable Area in Current Climate	RCP 6		RCP 8.5	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
Gaurishankar Conservation Area	692.35	0	0	0	0
Makalu Barun National Park	578.59	0.76	0	0	0
Sagarmatha National Park	558.67	0.76	0	0	0
Langtang National Park	420.16	0	0.75	0	0
Annapurna Conservation Area	343.2	68.37	48.82	0	0
Kanchanjunga Conservation Area	258.29	14.41	17.43	0	0
Manaslu Conservation Area	169.03	12.03	9.02	0	0
Dhorpatan Hunting Reserve	30.8	4.5	0.75	0	0
Api Nampa Conservation Area	0	31.08	19.24	0	0
Shey Phoksundo National Park	0	19.32	0	0	0
Banke National Park	0	0	0	0	0
Bardia National Park	0	0	0	0	0
Chitawan National Park	0	0	0	0	0
Khaptad National Park	0	0	0	0	0
Koshi Tappu Wildlife Reserve	0	0	0	0	0
Parsa National Park	0	0	0	0	0
Rara National Park	0	0	0	0	0
Shivapuri Nagarjun National Park	0	0	0	0	0
Suklaphanta National Park	0	0	0	0	0
Krishnashaar Conservation Area	0	0	0	0	0
Total	**3051.08**	**151.23**	**96.02**	**0**	**0**

Appendix 28: Potential suitable area (km^2) in protected areas for *Swertia nervosa*

Name	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
Gaurishankar Conservation Area	1950.48	0	0	0	0
Annapurna Conservation Area	1611.52	0	0	0	0
Langtang National Park	995.93	0	0	0	0
Kanchanjunga Conservation Area	880.47	0	0	0	0
Dhorpatan Hunting Reserve	714.24	0	0	0	0
Manaslu Conservation Area	694.66	0	0	0	0
Api Nampa Conservation Area	563.95	0	0	0	0
Sagarmatha National Park	350.88	0	0	0	0
Makalu Barun National Park	324.92	0	0	0	0
Khaptad National Park	177.43	0	0	0	0
Chitawan National Park	135.87	0	0	0	0
Parsa National Park	113.91	0	0	0	0
Shivapuri Nagarjun National Park	97.62	0	0	0	0
Bardia National Park	45.85	0	0	0	0
Rara National Park	32.03	0	0	0	0
Shey Phoksundo National Park	10.47	0	0	0	0
Banke National Park	4.53	0	0	0	0
Suklaphanta National Park	2.99	0	0	0	0
Koshi Tappu Wildlife Reserve	0	0	0	0	0
Krishnashaar Conservation Area	0	0	0	0	0
Total	**8707.73**	**0**	**0**	**0**	**0**

Appendix 29: Potential suitable area (km^2) in protected areas for *Swertia racemosa*

Name	**Suitable Area in Current Climate**	**RCP 6**		**RCP 8.5**	
		Suitable Area in 2050	**Suitable Area in 2070**	**Suitable Area in 2050**	**Suitable Area in 2070**
Annapurna Conservation Area	4319.78	4526.97	5027.59	5044.84	4961.23
Gaurishankar Conservation Area	1622.53	1443.83	1449.11	1444.56	1413.56
Shey Phoksundo National Park	1612.09	1403.57	1801.55	1712.99	2264.78
Kanchanjunga Conservation Area	1421.51	1756.88	1729.57	1730.32	1718.95
Manaslu Conservation Area	1344.33	1469.13	1468.38	1471.39	1460.86
Langtang National Park	1263.29	1353.74	1353.74	1352.99	1331.1
Api Nampa Conservation Area	1191.79	861.58	839.28	768.15	725.86
Makalu Barun National Park	1033.47	1112.1	1108.31	1110.58	1096.19
Sagarmatha National Park	956.18	1123.81	1124.57	1124.57	1125.32
Dhorpatan Hunting Reserve	625.34	503.69	483.4	478.14	398.51
Khaptad National Park	34.28	0	0	0	0
Rara National Park	20.1	0	0	0	0
Banke National Park	0	0	0	0	0
Bardia National Park	0	0	0	0	0
Chitawan National Park	0	0	0	0	0
Koshi Tappu Wildlife Reserve	0	0	0	0	0
Parsa National Park	0	0	0	0	0
Shivapuri Nagarjun National Park	0	0	0	0	0
Suklaphanta National Park	0	0	0	0	0
Krishnashaar Conservation Area	0	0	0	0	0
Total	**15444.68**	**15555.3**	**16385.5**	**16238.53**	**16496.36**

Appendix 30: Description of studied species for SDMs

1. *Swertia alata* (Royle ex. D. Don) C. B. Clarke: Fl. Br. Ind. 4:125 (1883). Chater in Enum. Of Fl. Plants of Nepal 3:164 (1982). Press *et al.* in Ann. Check. Fl. Pl. Nepal: 118 (2000). Shrestha *et al.*, in Pl. Nep.: 605 (2022).
Ophelia alata (Royle ex. D. Don) Griseb.

Annual herb, 15-20 cm (sometimes upto 50 cm); Tap root brown ; Stem erect, quadrangular, winged, branched or not; Leaves sessile to subsessile, blade narrowly ovate to cordate, 36 * 1.5-2.4 cm, apex acute, base attenuate; Inflorescence paniculate, pedicel 1-2 cm; Bract linear to lanceolate, 1.4 * 2 mm, apex acute, 1 vein, flower 4-merous; Calyx green, almost free, lobe linear to lanceolate, 0.8-1 cm * 0.1-0.2 cm, apex acute; Corolla yellowish white with purple veins or dots, lobe ovate to elliptic, 7-9 * 3-4 mm, apex acute; Gland 1 per lobe, watch pocket shaped with compound fimbrae; Stamen 4, filament 3-5 mm, anther oblong to ovate,1-1.5 mm; Carpel 7 mm, ovary ovoid, 4 mm, style indistinct, stigma capitates; Seeds polyhedral more or less rounded.

Distribution range: WCE Nepal, India, Pakistan.
Elevation: 1200-2500 m
Ecology: On the side of the stream or flowing water and also on rocky places.
Flowering/Fruiting: August- November

2. *Swertia angustifolia* Buch. - Ham. Ex D. Don: Prodr. Fl. Nep. 127 (1825). Clarke in Fl. Brit. India 4: 125 (1883). Malla *et al.*, in Fl. Of Langtang 161 (1976). Chater in Enum. Fl. Pl. Nep. 3: 96 (1982). Ting-nung and Pringle in Fl. China 16: 116 (1995). Grierson and Long in Fl. Bhu. 2 (2): 626 (1999). Press *et al.*, in Ann. Check. FI. Pl. Nep.: 117 (2000). Shrestha *et al.*, in Pl. Nep.: 605 (2022).

Ophelia pulchella D. Don
Swertia affinis C.B Clarke
Swertia angustifolia var. hamiltoniana Burkill
Swertia angustifolia var. pulchella (D.Don) Burkill

Annual herb, 20-80 cm; Yellow fibrous root; Stem erect, sub quadrangular, narrowly winged on angles, branched, glabrous; leaves sessile, leaf blade narrowly lanceolate to elliptic lanceolate, 2-6.2 * 0.2-1.2 cm, margin entire, base attenuate, apex acute, veins 1-3; Inflorescence many flowered with panicle of cyme, pedicel erect, 0.4-4.4 cm;

Bract linear to lanceolate, 0.52.3 cm * 1-2 mm; Flower 4-merous; Calyx green, almost free or sometimes tube of 1-1.5 mm, lobes linear or lanceolate, 1-1.5 cm * 1.4-2.4 mm, glabrous, entire, apex acuminate, 1-3 vein; Corolla white or yellowish with dark blue, purple or brown spot, tube 0.5-1 mm (2 mm), lobes elliptic or ovate, 4-10 mm * 3-6.5 mm, apex obtuse or apiculate; Glands 1 per corolla lobe, horse shoe shaped with an orbicular scale, many minutely hairy short fimbrae at apex of pocket; Stamen 4, filament 3.5-4 mm, nearly connate at base of ovary, hairy at base, anther ellipsoid ca.1mm; Ovary ovoid, 6-7 mm, style short, stout, stigma sub-orbicular; Seed polyhedral.

Distribution range: WC Nepal Bhutan, China, India, Burma, Vietnam.
Elevation: 100-3300 m
Ecology: Open slope land especially on the side of the trial reaching full sunlight.
Flowering/Fruiting: June- November

3. *Swertia ciliata* (D. Don ex G. Don) B.L. Brutt: Not. B.G. Edinb. 26: 272 (1965), Chater in Enum. Fl. Pl. Nep. 3: 96 (1982). Ting-nung and Pringle in Fl. China 16: 12 (1995). Grierson and Long in Fl. Bhutan 2 (2): 623 (1999). Press *et al.*, in Ann. Check. Fl. Pl. Nep.: 118 (2000). Shrestha *et al.*, in Pl. Nep.: 606 (2022).

Ophelia ciliata D. Don ex G. Don
Ophelia dalhousiana Griseb.
Ophelia purpurescens var. ciliata D.Don
Ophelia purpurescens Wall. Ex D. Don
Swertia purpurescens Boiss.

Annual herb, 30-55 cm; Root yellow fibrous; Stem erect, sub quadrangular, glabrous, branched; Leaves sessile or sometimes short petiolate, blade linear to lanceolate, slender with less width, 2-5 cm * 0.5-1.2 cm, margin slightly revolute, apex acute, base attenuate, veins 3-5; Inflorescence panicle of cyme, many flowered spreading, pedicel erect, 0.4-2.6 cm, Bract lanceolate to elliptic lanceolate, 1.8-2 cm * 2-3 mm, apex acute, veins 3, 5-merous; Calyx green, tube ca. 1mm, hairs present inside the tube, lobes linear to elliptic lanceolate, 2.56 mm * 1-1.5 mm, slightly unequal, margin and mid vein dark purple, apex acuminate; Corolla pale white with continuous purple band above gland in each petal, tube 0.5-1 mm, lobe ovate lanceolate, 5-6 mm * 1.2-3 mm, apex acuminate; Glands one per corolla lobe, horse shoe shaped, naked, two green spot above each gland; Stamen 5, filament dark purple, 4-5 mm, basally much enlarged and connate at the base forming a rim or tube, anther blue or purple, less than 1 mm; Carpel ca. 7 mm, ovary ovoid 3-5 mm, style distinct, 1.5 mm, stigma lobe capitates; Seed rounded to finely warted.

Distribution range: WCE Nepal, Pakistan, China, India, Afghanistan.
Elevation: 2500-4000 m
Ecology: On open flats, on the road trail as well as sloppy areas.
Flowering/Fruiting: July-November

4. *Swertia dilatata* C.B Clarke: Fl. Brit. India 4 (10): 122 (1883). Chater in Enum. F1. Pl. Nep. 3: 96 (1982). Malla *et al.*, Fl. Kath. Valley: 484 (1986). Press *et al.*, in Ann. Check. Fl. Pl. Nep.: 118 (2000). Shrestha *et al.*, in Pl. Nep.: 606 (2022).

Annual herb, 30-60cm (sometimes upto 100 cm); root yellow fibrous; Stem erect, hollow, sub quadrangular, narrowly winged, branched, glabrous; Leaves sessile to sub sessile, blade linear or linear to lanceolate, recurved downwards, 1.5-5.5 cm * 0.4-1 cm, margin entire, base attenuate, apex acute, veins 3; Inflorescence panicle of cyme, pedicel 2-12 mm, Bracts elliptic-linear, 13-20 mm * 2-3 mm, veins 3; Calyx green, sparsely ciliate, tube ca.1-2.5 mm, lobes lanceolate to elliptic lanceolate, 5-6 mm * 2-3 mm, apex acuminate; Corolla whitish with purple markings near the base, tube ca. 2mm, lobes ovate, 5-7 mm * 4-5.5 mm, apex acute; Glands one per corolla lobe, horse shoe shaped, naked, two green spot above each gland; Stamen 5, filament free, purple, 4-6 mm, anther ovate to oblong, ca. 1-1.5 mm; Ovary ellipsoid, 3-4 mm * 1-2.5 mm, style indistinct, stigma bifid; Seed rounded, warted.

Distribution range: WC Nepal, Bhutan, China, India, Burma, Myanmar.
Elevation: 1500-4000 m
Ecology: On scrubland, slopes, along the streams.
Flowering/Fruiting: August- September

5. *Swertia multicaulis* D. Don: Prodr. Fl. Nep. 127 (1825). C. B. Clarke in Fl. Brit. India 4: 129 (1883). Malla *et al.*, Fl. Of Langtang 162 (1976). Chater in Enum. Fl. Pl. Nep. 3: 97 (1982). Ting-nung and Pringle in Fl. China 16: 112 (1995). Grierson and Long in Fl. Bhutan 2 (2): 628 (1999). Press *et al.*, in Ann. Check. Fl. Pl. Nep.: 118 (2000). Shrestha *et al.*, in Pl. Nep.: 607 (2022).

Perennials, 8-12 cm; Long tap root, brown in color, diameter 1.4 cm; Stem ascending, many cespitose, striate, simple, caudex, sheathed by remains of old petioles, black in colour; Leaves mostly basal forming rosette, petiole flattened, 5-10 mm, leaf blade spatulate to oblong spatulate, 3-4 cm * 4-8 mm, margin scabrous, base connate, apex obtuse to rounded, veins 3-7, stem leaves in pair of 1 or 2, sessile, elliptic, 7-10 mm * 3-4 mm, apex obtuse, mid vein 1; Inflorescence raceme or umbel like, pedicel 2.2-6 cm, slightly winged, flower 4merous; Calyx green, tube 1mm, lobe lanceolate,4-7 mm * 2-3.5 mm, glabrous, apex acute to obtuse, vein-1; Corolla pale blue to purple, tube 1 mm, lobes oblong, 7-10 mm * 2-3 mm, tip pointed backwardly, apex obtuse; Glands 1 per corolla lobe, oblong to rhomboid, fimbriated; Stamen 4, filaments 4-5 mm, anther dark blue, ellipsoid, 2-5 mm, hairs present at the base; Ovary ovoid-ellipsoid, style indistinct, stigma suborbicular; Seed ovoid.

Distribution range: WCE Nepal, Bhutan, China
Elevation: 3000-4500 m
Ecology: On alpine meadows.
Flowering/Fruiting: July-November

6. ***Swertia nervosa*** (G. Don) C. B. Clarke: Fl. Br. Ind. 4: 125 (1883). Chater in Enum. Fl. Pl. Nep. 3: 97 (1982). Malla *et al.*, Fl. Kath. Valley: 484 (1986). Ting-nung and Pringle in Fl. China 16: 116 (1995). Grierson and Long in Fl. Bhutan. 2 (2): 626 (1999). Press *et al.*, in Ann. Check. Fl. Pl. Nep.: 118 (2000). Shrestha *et al.*, in Pl. Nep.: 607 (2022).

Agathotes nervosa Wall. Ex G. Don
Swertia cavaleriei (Wall. Ex G. Don) Griseb.

Annual herb, 20-80 cm; Root fibrous yellow brown; Stem erect, hollow, quadrangular and winged; Leaves sessile to sub sessile, blade elliptic to lanceolate, 2.5-4.8 cm * 0.6-1.4 cm, margin entire, base attenuate, apex acute, veins 1-3; Inflorescence panicle of cyme, pedicel 0.4-2.5 cm, Bracts linear to lanceolate, 0.5-2.2 cm * 3-6 mm, veins 1-3, flower 4-merous; Calyx green, tube 0.5-1 mm, lobes linear to lanceolate, 7-22 mm * 0.5-5 mm, apex acute; Corolla green or whitish with purple markings, tube 1-2 mm, lobes elliptic to ovate, 0.4-0.6 cm * 1.5-2 mm, apex acute; Glands 1 per corolla lobe, horse shoe shaped with pocket like flap, fimbriated at apex of gland; Stamen4, filament linear widening at base, more or less free, 2-4 mm, anther ovate or obtuse, ca. 1mm;

Carpel 0.7-0.8 cm, ovary ovoid 3-3.5 mm, style stout ca. 0.5 mm or less, stigma capitates; Seed polyhedral, warted.

Distribution range: WCE Nepal, Bhutan, India, China.
Elevation: 1000-3000 m
Ecology: Along streams, hillsides, scattered forests.
Flowering/Fruiting: June- September elliptic.

7. ***Swertia racemosa*** **(**Griseb.) C. B. Clarke: Fl. Br. Ind. 4: 124 (1883). Malla *et al.*, FI. Of Langtang 163(1976) Chater in Enum. Fl. Pl. Nep. 3: 97 (1982). Ting-nung and Pringle in Fl. China 16: 123 (1995). Grierson and Long in Fl. Bhutan 2 (2): 625 (1999). Press *et al.*, in Ann. Check. Fl. Pl. Nep.: 118 (2000). Shrestha *et al.*, in Pl. Nep.: 607 (2022).

Annuals, 8-50 cm; Roots yellow, fibrous; Stem erect, hollow, ribbed, glabrous; Leaves sessile, blade linear-lanceolate, 2.3-7 * 0.4-1.6 cm, dorsal glabrous and ciliated on veins only towards ventral surface, margin entire, ciliate, Base auriculate and sub amplexicaul, apex acute, vein 3, strigose when young but spreading after; Inflorescence panicle of cyme, pedicel erect 1 cm-2.2 cm, Bracts lanceolate to linear-lanceolate, 1.8-3.2 cm * 1-7 mm, flower 5 merous; Calyx green, tube campanulate,3-4mm, lobes triangular to lanceolate, margin ciliate, 4.5-12 mm * 2-3 mm, unequal, mid vein 1-3; Corolla pale blue to purple, tube campanulate, 2.53 mm, lobes ovate to elliptic, 9-10 * 6.5-7 mm, apex acute; Glands 1 per corolla lobe, oblong, fimbriated; Stamen 5, filament basally white, apically blue,4.5-5.5 mm, basally much enlarged, connate, anther blue 1-1.2 mm, ellipsoid; Carpel 7-10 mm, Ovary ovoid, 6-8mm, Style 1.5-2 mm, slender, Stigma lobe capitates; Seed smooth ellipsoid .

Distribution range: WC Nepal, Bhutan, China, India
Elevation: 3200-4400 m
Ecology: On open meadows and scrubland, along forest.
Flowering/Fruiting: August- September