

CLIMATE CHANGE AND SHIFTING DISTRIBUTION PATTERNS OF GYMNOSPERM SPECIES IN THE HAZARA REGION

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DOI: <https://doi.org/10.5281/zenodo.22690353>

Keywords

Climate Change, Gymnosperm Species, Species Distribution Patterns, Hazara Region, Himalayan Ecosystem, Biodiversity Conservation, Forest Ecology, Elevational Shift, GIS, Species Distribution Modelling (SDM)

Article History

Received: 30 January 2026

Accepted: 15 March 2026

Published: 31 March 2026

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Abstract

One of the greatest environmental concerns affecting biodiversity and ecosystems all over the world is climate change. Changes in temperature and precipitation impact a wide variety of ecosystems, and mountainous ecosystems are possibly the most sensitive. The west Himalayan region of Pakistan, the Hazara Region, contains an array of forests that have populations of important gymnosperm species. Gymnosperms influence the forest ecosystem and have important roles in maintaining structural integrity and serve as important components of local ecosystems. Temperature, precipitation, and climate changes influence the range of gymnosperms, their regeneration, and the fitness of their habitats. My research looks at how climate change impacts gymnosperms in the Hazara Region. This begins with assessing current ranges, determining the climatic factors that influence gymnosperm habitat preference, and identifying range shifts with new potential climate conditions in mind. Relationships of climate variables and observed species occurrences rely heavily on field investigations, climatological data, ecological observations, and certain specialized techniques like GIS and SDM. My primary focus is to better understand how important gymnosperm species change their elevational distribution, habitats, and the threats caused by the range shifts due to climate change. My research looks under-studied yet significant topics dealing with climate change and the vegetation of mountain ecosystems. The results will also help strengthen the conservation of biodiversity and the management of forest ecosystems in the Hazara Region of Pakistan.

INTRODUCTION

Climate change poses global threats to ecosystems and the distribution of species. Phenomena such as the increase in average temperatures, changes to the intensity and distribution of rainfall, changes to extreme weather events, and shifts in the seasonal cycle all affect ecological processes and the survival of all species. Many mountain ecosystems experience these phenomena most acutely, as many species in these areas have low adaptive capacities and narrow ecological ranges. According to the IPCC, observed impacts of climate change on terrestrial and freshwater

ecosystems include changes to species' distribution, abundance, and ecological interactions and responses (IPCC, 2022).

Among all the organisms, plants demonstrate the largest responses to environmental changes. Plants need specific environmental conditions to

grow, reproduce, and regenerate. The suitability of a habitat is largely determined by the availability of water and the quality of the surrounding soils. Changes in temperature and rainfall affect ecosystem productivity. Many plant species are known to respond to changes in

climate by moving to higher elevations in order to stay within their required climate. The impacts of climate change on the movement of species has already been documented and is especially pronounced in mountainous regions, where warming temperatures in low elevations leads species to move to higher and cooler areas (Lenoir & Svenning, 2015).

Gymnosperms are ancient groups of vascular plants that contain conifers. Gymnosperms perform many essential functions in forest ecosystems including carbon storage, soil protection, and habitat formation. Many species are adaptive to certain climatic and elevation conditions, and, as a result, are sensitive to environmental changes. Some species that are integral to the ecosystems of the Himalayan region include Pindrow fir (*Abies pindrow*), Himalayan Spruce (*Picea smithiana*), and Silver fir (*Cedrus deodara*). They are important for the habitats and have many economic benefits. Many of these species are impacted by changes in climate as well as disturbance to their habitat. Growth and regeneration are impacted by changes in climate and the movement of these species to other areas (Shrestha et al. 2012).

Many of mountain regions' plants are negatively impacted by climate change first. Since many species are limited to certain areas, girder temperature increases makes plants start to move to higher elevations. However, plants moving to higher elevations are restricted by the available space, increased competition, and habitat fragmentation. High elevation species become increasingly vulnerable to loss of their habitats and decline of their population. According to the IPCC (2022), the mountain regions' biodiversity is negatively impacted by climate changes and most species are showing evidence of changes in their populations and distribution.

Pakistan is home to mountain ranges that support diverse forest ecosystems, including the western Himalayan forests of Khyber Pakhtunkhwa. The Hazara Region has a mixture of high elevation and low elevation climate regions, and is home to coniferous forests. Coniferous forests provide the ecosystem and human community with numerous benefits,

including the protection of soil and water resources, the removal of carbon from the air, and the sustainment of habitats that support a diverse flora and fauna. While these ecosystems provide many benefits, climate change is placing these services at risk with increasing temperatures, changes in rainfall and drought, and shifts in ecosystems.

Background of the Study

Climate change destabilizes biodiversity and natural ecosystems all across the globe. Increases in average temperatures and a shifting rainfall pattern cause disruptions in ecosystems and affect the placement of most land plants. Climate change causes shifts in growing conditions including the survival and regrowth of a plant, alterations in its distribution as well as its geography.

Affectionately known as the guardians of the forest, gymnosperm species provide various economic, ecological and environmental benefits to forest ecosystems within mountainous regions. They play a role in the structure of a forest, aid in the storage of carbon, help to preserve soil from being eroded, and help to maintain equilibrium of a variety of wildlife. Yet, the impacts of climate change pose new problems on gymnosperm populations as changing climates and conditions alter their preferred habitats and natural dispersal patterns.

The Himalayan region of Pakistan contains essential elements of the western Himalayan ecosystem, specifically the coniferous forests dominated by gymnosperm species. These forests are subjected to different combinations of factors such as altitude, temperature, and precipitation as well as human activity. Understanding the impact of climate change on gymnosperm has great potential for understanding of other impacts of climate change and the development of methods of conservation for the ecosystem.

Research Problem Statement

Shifts in climate are creating unprecedented conditions for plants to both grow and survive. This poses a particular risk for the Gymnosperms of the Hazara Region due to how temperature,

precipitation and changes to habitat will all impact them. There is also a lot of research on how climate change is currently shaping the distribution of gymnosperms and also how it will affect them in the future. Because of the gap in thorough research on the impacts of climate change on the distribution of plant species, it is almost impossible to create a framework for controlling and monitoring the ecosystem and its wildlife. This also means true understanding of the Gymnosperms will also be difficult to achieve, and creating effective conservation for them will be even more difficult.

Research Objectives

1. To identify the major gymnosperm species present in the Hazara Region.
2. To analyze the current distribution patterns of gymnosperm species.
3. To evaluate the influence of climatic factors on gymnosperm distribution.
4. To assess potential changes in species distribution under future climate scenarios.
5. To identify conservation challenges and management strategies for gymnosperm species.

Research Questions

1. What are the major gymnosperm species distributed in the Hazara Region?
2. How are climate variables influencing the distribution patterns of gymnosperm species?
3. Are gymnosperm species shifting their distribution ranges due to climate change?
4. Which climatic factors have the strongest impact on gymnosperm habitat suitability?
5. What conservation strategies can help protect gymnosperm species under changing climate conditions?

Significance of the Study

This study contributes to understanding the effects of climate change on gymnosperms in the Hazara Region. With the knowledge of changing species distributions, one can identify vulnerable species and ecosystems in need of conservation. The study contributes to the field of ecology by describing the response of the mountain forest ecosystem to changing climate. These findings

can help forest management agencies, conservation organizations, and researchers to formulate measures for conservation of biodiversity and sustain ecosystem services.

Scope and Limitations of the Study

This study looks at how climate change effects gymnosperm species in the Hazara region. It analyzes how climate effects habitats and how gymnosperm species may move. This study relies on many types of ecological and spatial analyses.

The main limiting factors for this study are the availability of long term climate data, accessing remote wooded areas, seasonal differences in climate, and the effect of human caused factors such as land use on the environment. These problems do not stop the study and allow researches to describe what is happening to the gymnosperm ecosystems.

LITERATURE REVIEW

As the world's foremost environmental concern, climate change is having substantial impacts on biodiversity and ecosystem dynamics. Changes in temperature, changes to regimes of precipitation, and the increased occurrence of extreme weather events affect natural systems at different temporal and spatial scales. Of the ecosystems around the world, mountain ecosystems are most vulnerable. These ecosystems have high diversity and are strongly influenced by elevation and climate. The species of plants that are found in mountain regions have especially narrow geographic distributions, making them very sensitive to climate change.

One of the primary impacts of climate change on vegetation communities is reconfiguring growing conditions, as well as reproductive and regenerative ability and the balance of competitive relationships. Because temperature is the primary driver for distributions of plant communities and controls the physiological limits of a species, shifts in temperature and rainfall can greatly affect the geographic extent of habitats of plant species, sustaining some species and affecting others negatively. According to Parmesan and Yohe (2003), shifts in the distribution of species and seasonal events in

biological systems have been observed in different ecosystems due to climate change.

Mountain forests help store carbon, protect soil, regulate water flow, and support rich biodiversity. These forest ecosystems help to mitigate the adverse impacts of climate change. Vegetation zones are changing, and climate change is causing changes in the range and composition of species. Many studies have shown the upward shifts in the ranges of plants to find more suitable climates to survive. Lenoir and Svenning (2015) note that some plants have started moving to higher elevations and latitudes. However, there are several factors that determine the ability of some plants to move to new locations, such as available spaces and the species' characteristics.

Gymnosperms are a major component of mountain forests in cooler environments. Gymnosperms are a diverse group of plants that have the ability to adapt to cool climate conditions. Gymnosperms play an essential role in the forest ecosystems by helping to grow the ecosystem and sequester carbon. Stable

ecosystems are maintained by conifer species of *Cedrus deodara*, *Pinus wallichiana*, *Abies pindrow*, and *Picea smithiana*.

Concept of Climate Change and Global Temperature Trends

Climate change encompasses significant shifts in long-term regularity in the Earth's climate, including changes in temperature, precipitation, weather patterns, and the concentration of extreme weather events. Although climatic shifts occur naturally, much of the current climate change is attributable to human activity, primarily an increase in the release of greenhouse gasses into the atmosphere as a result of fossil fuel consumption, industrial activity, deforestation, and changes in land use. Greenhouse gasses, principally carbon dioxide, but also methane and nitrous oxide, absorb energy emitted by the earth and radiate it back to the atmosphere, trapping energy in the lower atmosphere, causing temperatures to rise (IPCC, 2022).

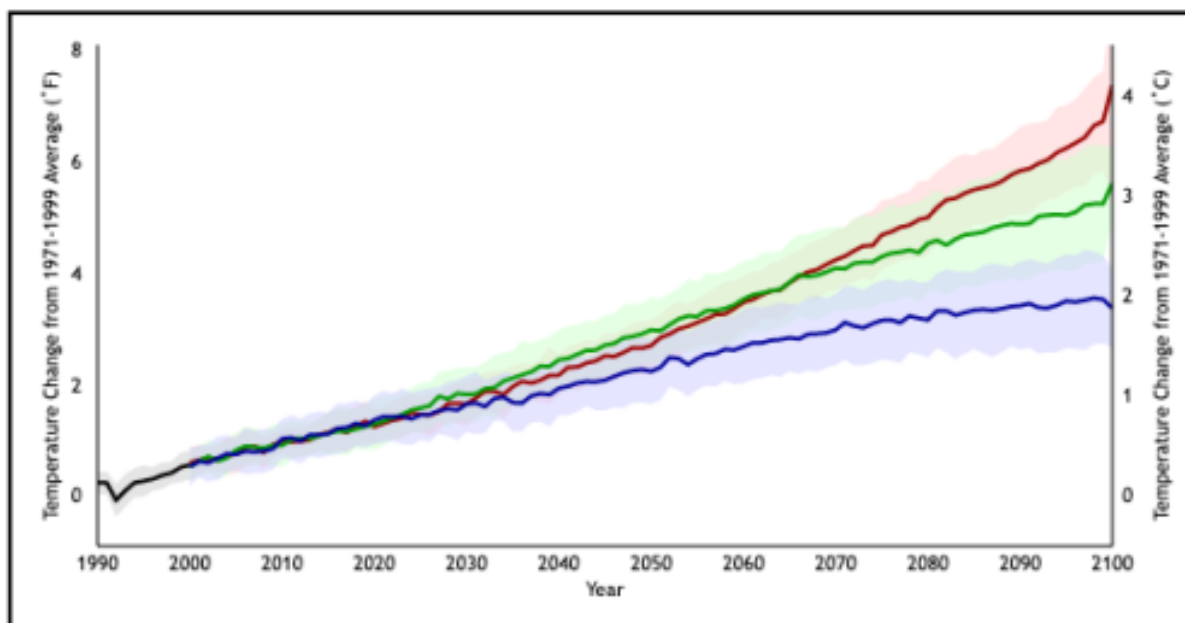


Fig 2.1 Concept of Climate Change and Global Temperature Trends

In the last century, particularly in recent decades, there has been a rise in average temperatures and

a shift to more extreme temperatures. Increasing temperatures impact ecosystems and biological

processes. The IPCC (2022) reports that within the last century, the global average temperature has increased and will further increase, causing an array of new challenges to ecosystems.

Effects of Climate Change on Forest Ecosystems

Forest ecosystems are greatly impacted by climate change and will continue to deteriorate without strategic intervention. Forests are the world's largest carbon sink, provide ecosystem services, protect soil resources, and maintain biodiversity. As climatic conditions continue to change, forest productivity and ecosystem stability will be further impacted.

Alterations in temperature, precipitation, and their distributions will change the way forests grow, and even their ability to survive. Rising temperatures will cause water stress, especially in drier and more arid regions. Prolonged periods of drought will also decrease tree growth and lead to increased mortality rates. Declaring forests more susceptible to drought-related pests, pathogens, and wildfires.

Much of the world's plant and animal species are adapted to live in very specific and narrow ranges of climate. This is especially problematic for mountain forests where trees have very narrow climatic optima. As species attempt to move with a shifting climate toward more favorable environments, they will encounter barriers like disjoint habitats, human induced disruption, and geological barriers. Mountain forests are also at an increased risk of losing conifer species.

Climate Change Impacts on Plant Species Distribution

Distribution of plants is vastly dependent on factors such as temperature, precipitation, elevation, and soil type. Alteration of climate leads to changes of these factors and consequently shifts in the preferred habitats, and therefore, the geographic ranges of plants. Several studies have documented plants as responding to climate change by migration, adaptation or population decline.

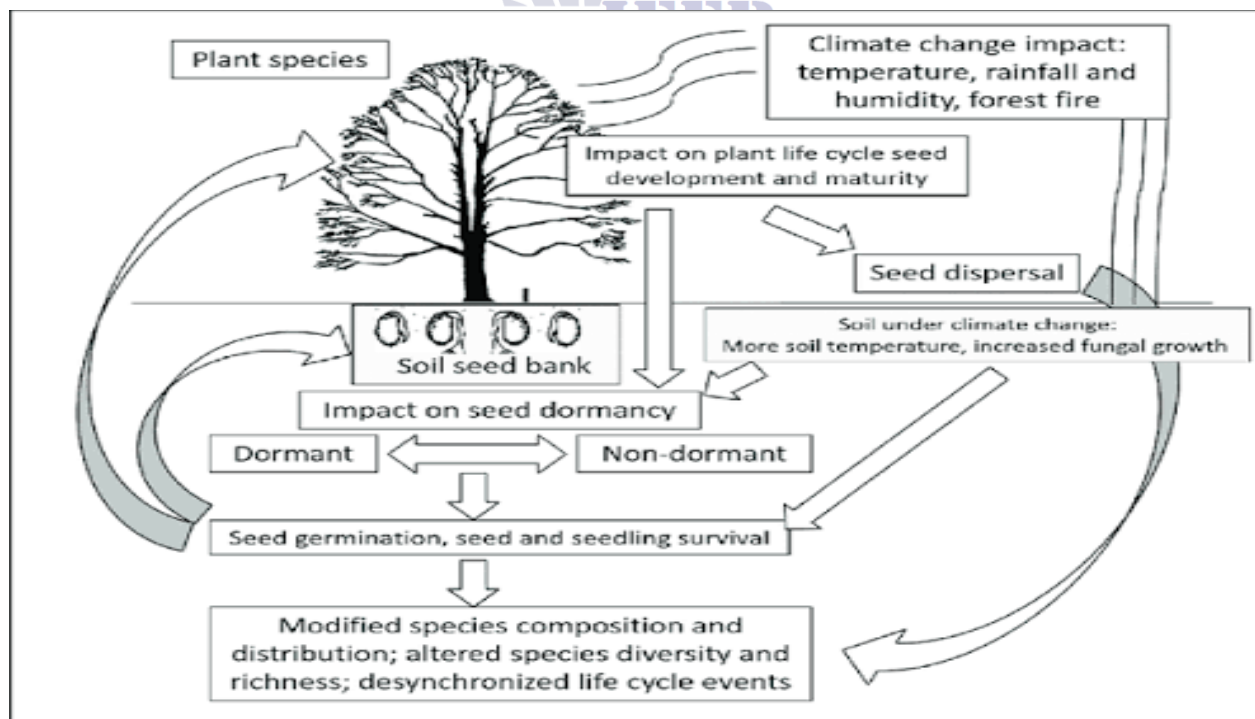


Fig 2.2 Climate Change Impacts on Plant Species Distribution

Many plants have already shifted toward colder climates such as high elevations. Unaided by this

movement, plant species living at mountainous high elevations may eventually run out of space and resources.

Because many plant species have varying levels of ecological and climate tolerances, climate change may favor some while negatively impacting others. Species with high climate tolerances may expand their favored habitats, while the more specialized species may decline. Parmesan and Yohe (2003) also reported that climate change has already affected the distribution of species across ecosystems and affected other biotic components.

Ecological Characteristics of Gymnosperm Species

Gymnosperms are an ancient group of vascular plants producing naked seeds and have many economically important members like conifers. They are major components of tree communities of many temperate and mountainous forests. Gymnosperms have unique ecological traits like tolerance to cold and growth in soils with low fertility.

The possession of traits like needle-shaped leaves, thick bark, deep roots, and efficient water use helps them to tolerate some of the harshest

climatic conditions. Therefore, they are important components of mountain forests.

Many gymnosperms have deep roots and thick bark which help to retain water, along with needle-like leaves, so they reduce water loss and conserve water more efficiently. Gymnosperms also stabilize the soil to a great extent, thereby maintaining the ecosystem. Certain species, like *Cedrus deodara* and *Pinus wallichiana*, are important conifers to the Himalayan forests.

The presence of adaptations to cope with climate does not provide complete protection to gymnosperms from the threats posed by rapid climate changes. Meteorologically more unpredictable climatic conditions endanger seed germination and seedling establishment.

Global Studies on Climate Change and Gymnosperm Distribution

There has been a plethora of research done on climate change's impact on gymnosperm distribution. Several studies have shown how warming temperatures and shifting precipitation patterns are forcing conifers to change their range. This is especially visible in the mountain ranges as climate zones move towards the upper

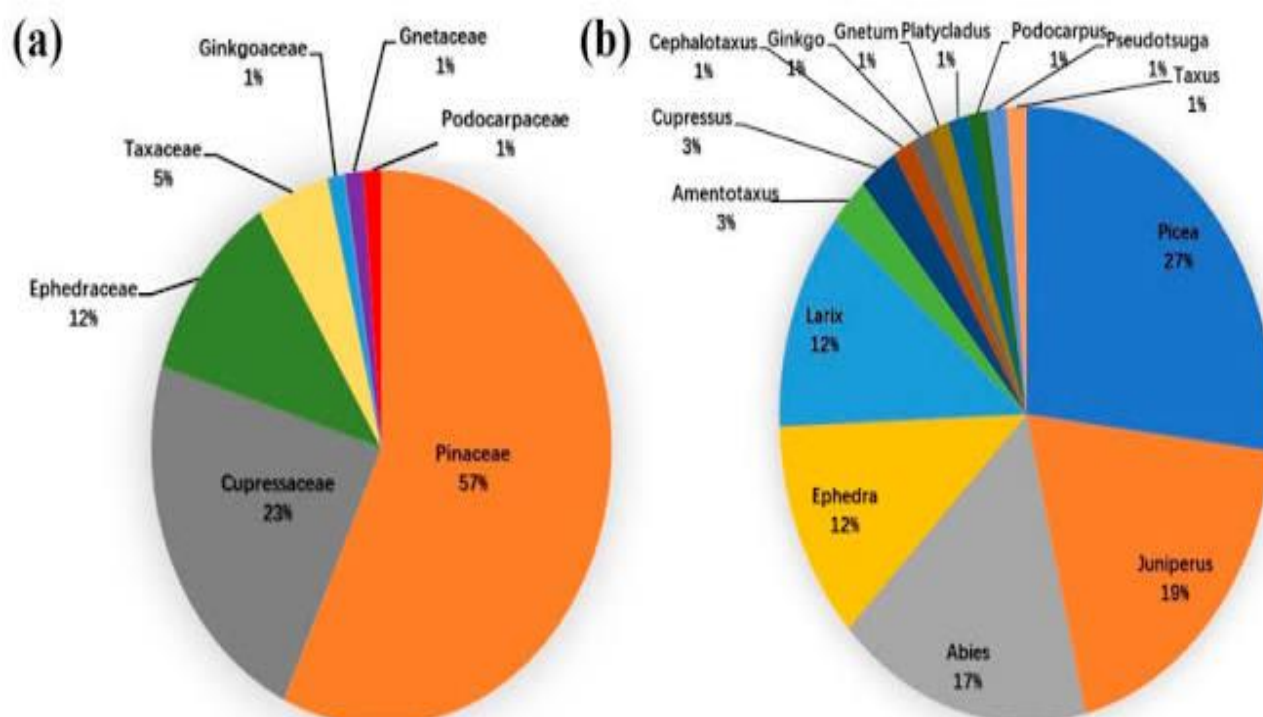


Fig 2.3 Global Studies on Climate Change and Gymnosperm Distribution

The different studies conducted in different countries have shown that conifers have different responses to climate change based on their ecology and adaptability. Some have been able to move up range, while others are declining due to the increasing pressure on the environment. High elevation gymnosperms are especially vulnerable since they have very few options for possible new territory.

Studies predict that in the future, the ranges of many conifers will shift due to climate change and that many gymnosperms will not have adequate new range available to them. For these predicted scenarios, possible conservation and management practices may be put in place to help keep these and related dependent ecosystems viable.

Worldwide research conclude that to analyze climate change on gymnosperm populations, there must be a combination of field studies, climate work, and a method of spatial modeling. When these elements are brought together, they can give insights into future evaluation of ecosystems and where species are the most at risk.

Gymnosperm Diversity in Pakistan

Pakistan has many mountain ecosystems and many types of gymnosperm in the northern regions. The Himalayan, Hindu Kush and Karakoram mountain ranges have niches for many important coniferous species. These forests are important ecological systems because they support other species and systems, help regulate water systems, and help sustain local populations. In Pakistan, the major gymnosperm species are *Cedrus deodara*, *Pinus wallichiana*, *Pinus roxburghii*, *Abies pindrow*, and *Picea smithiana*, and they all help define forest systems in varying climates and elevations.

The distribution of gymnosperms depends on many factors including the temperature and precipitation of the climate and the type of soil. Despite these factors, many forest systems face the problems of climate change, deforestation, intensive use, and changes in land use. Temperature and rainfall climates can directly change the regrowth patterns of these species.

Research on Pakistani gymnosperms has addressed forest ecology and conservation as well as assessments of biodiversity. Although,

thorough analyses of climate change and how gymnosperm systems relax to new climate conditions in specific regions of Pakistan, such as Hazara, have been overlooked.

Forest Ecosystems of the Himalayan and Hazara Regions

The Himalayas are home to some of the world's most valuable ecosystems. They are characterized by towering mountain ranges that are historically home to diverse ecosystems and biodiversity. Within the Himalayas, we see ecological zones that span from tropical to subalpine ecosystems. Many regions in the Himalayas have climax forests that span across the region and support dominating species within a variety of genera such as Gymnosperms. These forests aid in the conservation of soil, decomposition, and the routine of water all while storing carbon.

Forests in the region, however, are extremely vulnerable to changes in climate. Many of the Himalayan forests flourish within a very specific climate in regard to both temperature and precipitation.

The forests of the western Himalayas, as with the other ecosystems, are constantly changing due to the combined effects of global warming and human-based activities. Altered rainfall patterns, increased temperatures, and modifications to the environment will change the vegetation and the geographic range of gymnosperm species within the region.

Previous Research on Vegetation Shifts in Mountain Areas

Studies on shifting mountain vegetation show how climate change alters plant distributions and ecosystems. The impacts of climate change on vegetation have been well documented by analysis of thermal gradient shifts in vegetation zones.

Many studies have recorded an upward shift in the vertical distribution of plants as a result of climate change (mostly warming). The majority of these shifts suggest that plants are responding to changes in climate by moving in the direction of more favorable conditions. However, the ability to migrate varies among plants depending on their dispersal tendencies, suitable growing conditions, and how flexible they are to environmental changes.

Climate change has been observed to affect the structure and composition of forests in the Himalayan regions and elsewhere. Changes in vegetation are also likely to affect various important functions of ecosystems by limiting the available niches for interactions among plants and by changing habitat availability for affinity, or specialized, plants.

Other studies emphasize the importance of developing climate-based models and conducting long-term studies to determine future impacts of climate change on vegetation. The importance of these studies is apparent in the Hazara region. These forests support mountain ecosystems and provide important ecological services as well as habitat for various threatened gymnosperm species. To reduce the threat of climate change on mountain ecosystems, research studies on climate change and its effect on different species are necessary in order to create effective conservation methods.

MATERIALS AND METHODS

An ecological research framework is used to analyze the impacts of climate change on shifting distributions of gymnosperm species found in the Hazara Region. Field-based vegetation surveys, climatic data, and spatial modeling allow evaluation of the impact of changing conditions on the distribution of gymnosperm.

Table 4.1: Summary of Field Sampling Sites

Sr. No.	Sampling Site	Elevation (m)	Forest Type	Number of Plots
1	Abbottabad	1200–2200	Mixed Conifer Forest	10
2	Mansehra	1500–3000	Temperate Forest	12
3	Kaghan Valley	1800–3500	Alpine Conifer Forest	15

Sr. No.	Sampling Site	Elevation (m)	Forest Type	Number of Plots
4	Balakot	1000–2200	Sub-Tropical Forest	8

Quantitative and spatial methods are used to examine the current distribution of species and project potential future distribution under different climate change scenarios. Using ecological observations, along with Geographic Information Systems (GIS), remote sensing, and species distribution modeling, climatic data are analyzed and related to the occurrence of different species. The research provides an analytical framework to study the impact of climate change in mountain forest ecosystems.

Field Survey and Sampling Methods

To document occurrence, abundance, and distribution of gymnosperm species, field surveys are done throughout the Hazara Region. With field observations, and with certain vegetation characteristics in mind, observations are made about the presence of vegetation, elevation ranges, and the condition of the habitat.

Table 4.2: Vegetation Parameters Recorded During Field Survey

Parameter	Measurement Unit	Method Used
Species Presence	Number of species	Field observation
Tree Density	Trees/hectare	Quadrat method
Tree Height	Meter (m)	Clinometer
Diameter at Breast Height (DBH)	cm	Measuring tape
Regeneration Status	Seedlings/ha	Field counting

To ensure a broad and thorough representation of forest types and elevation zones, sampling is done using ecological sampling techniques. After selecting a location, data is collected about the tree species and the population and the stage of the tree species.

Field surveys document precise locations, the slope of the area, and environmental conditions. Data from surveyed sites set an expectation about

the range of known distributions of the species, and models of the species' possible distribution.

Selection of Sampling Sites

Sampling sites are chosen based on ecological value, vegetation diversity, elevation, and accessibility in the Hazara Region. The sampling framework tries to target all the different zones of the forest to account for the range of climatic and environmental conditions.

Table 4.3: Climate Variables Used for Species Distribution Analysis

Climate Variable	Unit	Importance
Mean Annual Temperature	°C	Controls species growth
Annual Precipitation	mm/year	Determines moisture availability
Maximum Temperature	°C	Indicates heat stress
Minimum Temperature	°C	Determines cold tolerance
Elevation	Meter (m)	Represents climatic gradient

We choose sampling sites from the major areas of gymnosperm-dominant forests, and from places where the species *Pinus wallichiana*, *Cedrus*

deodara, *Abies pindrow*, and *Picea smithiana* occur. To investigate possible changes in the

distribution of species, we incorporate sites at different elevations.

The location of sampling sites is recorded using a GPS. This spatial data is employed for mapping distribution of species, and integrates field observations with GIS data analysis.

Identification of Gymnosperm Species

Identification of gymnosperms is performed through the combination of field observations, morphological characteristics, and known taxonomic references. The identification is primarily based on the structure of leaves, bark, cones, reproductive structures, all the morphology of a gymnosperm, and tree structures.

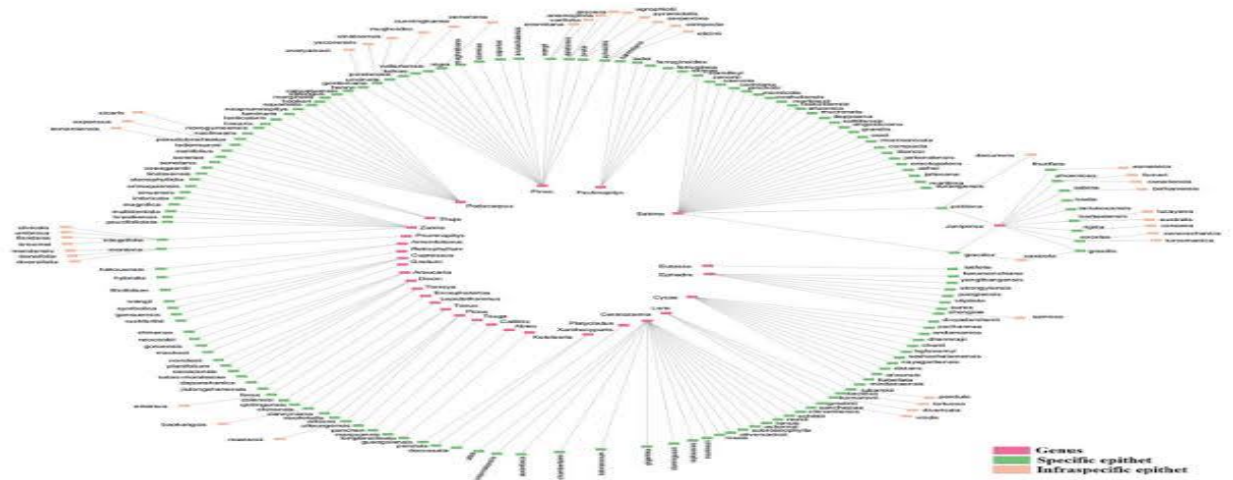


Fig 4.1 Identification of Gymnosperm Species

Field data are compared with published botanical identification guides and taxonomic literature for final confirmation of the species identity. The scientific name and classification of the observed species are also checked with standard botanical references.

The correct identification of gymnosperms is important for analysis of the distribution of gymnosperm species and the responses of individual gymnosperm species to climate change.

Data Collection Methods

Data can be collected from field surveys, climatic databases, satellite images, and even published ecological data. Adding multiple datasets to a single analysis helps calculate the impacts of the climate on the distribution of gymnosperms.

Collected data may include the occurrence of species, the environment, climatic variables, and historical distribution. These separate datasets are prepared and ready for spatial analysis and statistics.

Vegetation Data Collection

Field surveys collect vegetation data from selected sampling sites. Data collected includes vegetation plus tree count, regrowth status, and type of vegetation present.

For each sampling plot, information is collected regarding the occurrence of gymnosperm and the ecological characteristics. To assess the population, the measurements of diameter, height, and the characteristics of older and younger trees can be recorded.

Vegetation data can be used to analyze current data on the spatial distribution and to describe the relation of species to the environment.

Climate Data Collection

We analyze climate data from reputable sources in meteorology and climate databases to monitor climate changes. The following variables are of interest: temperature, precipitation, humidity and other environmental determinants that affect the distribution of plants.

Long-term climate changes in the region and observed trends are studied by analyzing

historical climate data. The impact of temperature and precipitation on the habitat of gymnosperms is also studied.

Assessments of possible variations in the distribution of species in future environmental conditions may also be made by using available climate change scenarios and projections.

Historical Distribution Data

Data on distribution in the past is collected from research articles, forest inventories, and other sources. These resources provide data on previous locations and distribution for several gymnosperm species.

Changes in distribution of species range and abundance over time, and elevation changes, may be identified by comparing historical data to new data collected by field observations. These field observations provide insight about potential impacts of climate change on species movements and the modification of habitats.

Use of Remote Sensing and GIS Techniques

Remote sensing and Geographic Information System (GIS) techniques analyze spatial trends in gymnosperm distribution and changes in the environment. Remote sensing from satellites captures landscape data, vegetation, and changes in forests.

GIS techniques can be used to make distribution maps and analyze elevation data. GIS techniques can integrate several data to map the occurrences of particular species and be used to analyze climate and geography. Spatial analysis helps in determining the locations of potential habitats and locating regions with environmental stress.

Remote sensing surveys are used to analyze changes in vegetation over a big area to help understand the effects of climate change on a variety of forest ecosystems.

Species Distribution Modelling (SDM)

Species Distribution Modelling (SDM) is used to assess the relationship between the occurrence of gymnosperms and environmental characteristics. With SDM, presence data of a species is integrated with climate and geography data to develop a model to determine the most likely areas of occurrence.

The model accounts for the effects of temperature, precipitation and other environmental variables, and builds upon several of the factors to develop habitat suitability maps and project the potential future distribution of the species.

SDM provides insight regarding gymnosperm habitats that are subject to reduction, those that may undergo an increase in range, and where conservation efforts should be prioritized for the gymnosperms that are most vulnerable.

Climate Variables Analysis

Research studies on gymnosperm dispersion analyze the influence of climate variables. Key climate variables in these studies include

- Mean annual temperature
- Temperature extremes
- Annual precipitation
- Precipitation seasonality
- Temperature variation
- Climatologically where temperature changes with elevation

Understanding the association of these climate variables and the occurrence of species helps delineate the major drivers of gymnosperm dispersal.

The objective of studying the impact of climate change and its implications on forest vegetation is to analyze changing environmental conditions and their likely impact on forest vegetation.

Statistical Analysis

The relationships between climate variables and the distribution of gymnosperms are evaluated using methods of statistics. Research methods and data sets determine the selection of analysis methods.

To gauge abundance and distribution of a species as well as environmental condition, statistics such as the mean, median, and mode may be used. Correlation and regression analysis are employed to delineate the relationship between the variables of climate and the occurrence of a given species.

To evaluate significant differences among the distributions of species along different elevation

sectors and the effect of climate, statistics pertaining to species distributions may be used. Performance of the Species Distribution Models are assessed.

The integration of statistics, GIS and ecological modeling addresses the climate induced changes in the distribution of gymnosperms across the region of Hazara.

RESULTS ANALYSIS

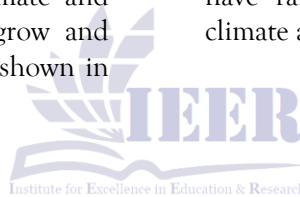
The findings from the study on gymnosperm distribution in the Hazara Region show specific trends related to elevation, climate, and habitat. The species of gymnosperms described show differences in their range due to differences in climate, rainfall, soil, and other factors.

Table 5.1: Current Distribution of Gymnosperm Species Along Elevation Gradient

Species	Lower Elevation (%)	Middle Elevation (%)	Higher Elevation (%)
<i>Cedrus deodara</i>	20	55	25
<i>Pinus wallichiana</i>	15	45	40
<i>Abies pindrow</i>	5	35	60
<i>Picea smithiana</i>	10	40	50
<i>Pinus roxburghii</i>	70	25	5

The analysis of the distribution of conifers shows that most of the species are found in a certain band of elevation over a band of climate and conditions that allow the species to grow and renew themselves. Some of the species shown in

the study, such as *Cedrus deodara*, *Pinus wallichiana*, *Abies pindrow*, and *Picea smithiana* have ranges and preference based upon both climate and weather and other ecological factors.



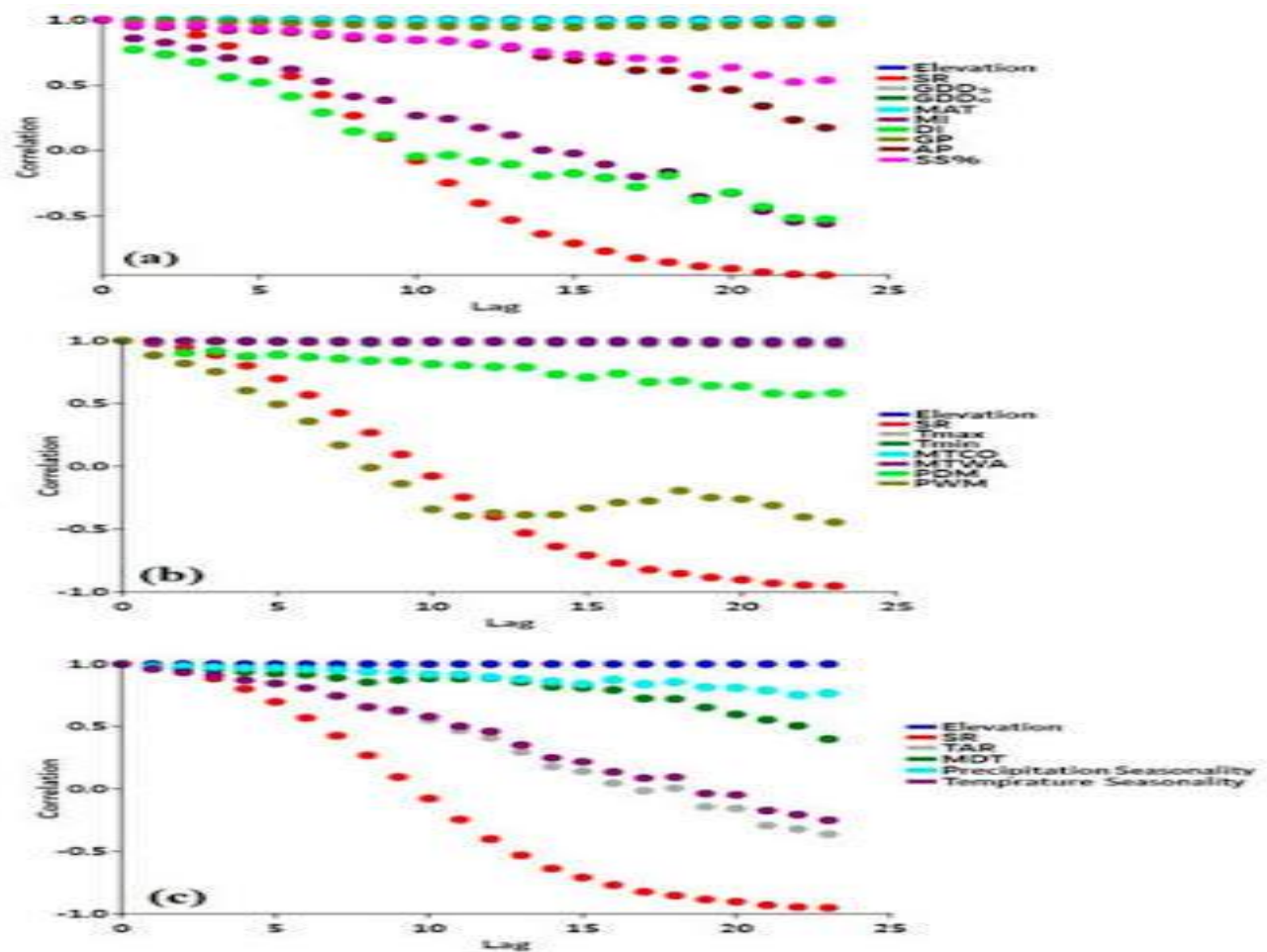


Fig 5.1 Current Distribution Patterns of Gymnosperm Species

Analysis of data done via GIS shows that certain forest areas in the Hazara Region have different species of gymnosperms. There is a greater presence of gymnosperms in areas where climate is favorable and forests are well established, with a relative lack of species in places that are environmentally more stressful.

Diversity and Abundance of Gymnosperm Species

Analysis of gymnosperm diversity shows mostly common conifer species found in the forests of the Hazara region. The variation in species composition is the result of differences in the forest environment, level of disturbance, and the structures of the forests.

Table 5.2: Species Diversity and Relative Abundance

Species	Number of Individuals Recorded	Relative Abundance (%)
<i>Cedrus deodara</i>	245	32.6
<i>Pinus wallichiana</i>	210	28.0
<i>Abies pindrow</i>	145	19.3
<i>Picea smithiana</i>	95	12.6
<i>Pinus roxburghii</i>	55	7.5

Different species show differing levels of abundance with some species showing physiological tolerance to a broad range of

environmental conditions and some species of gymnosperms being restricted to specific habitats.

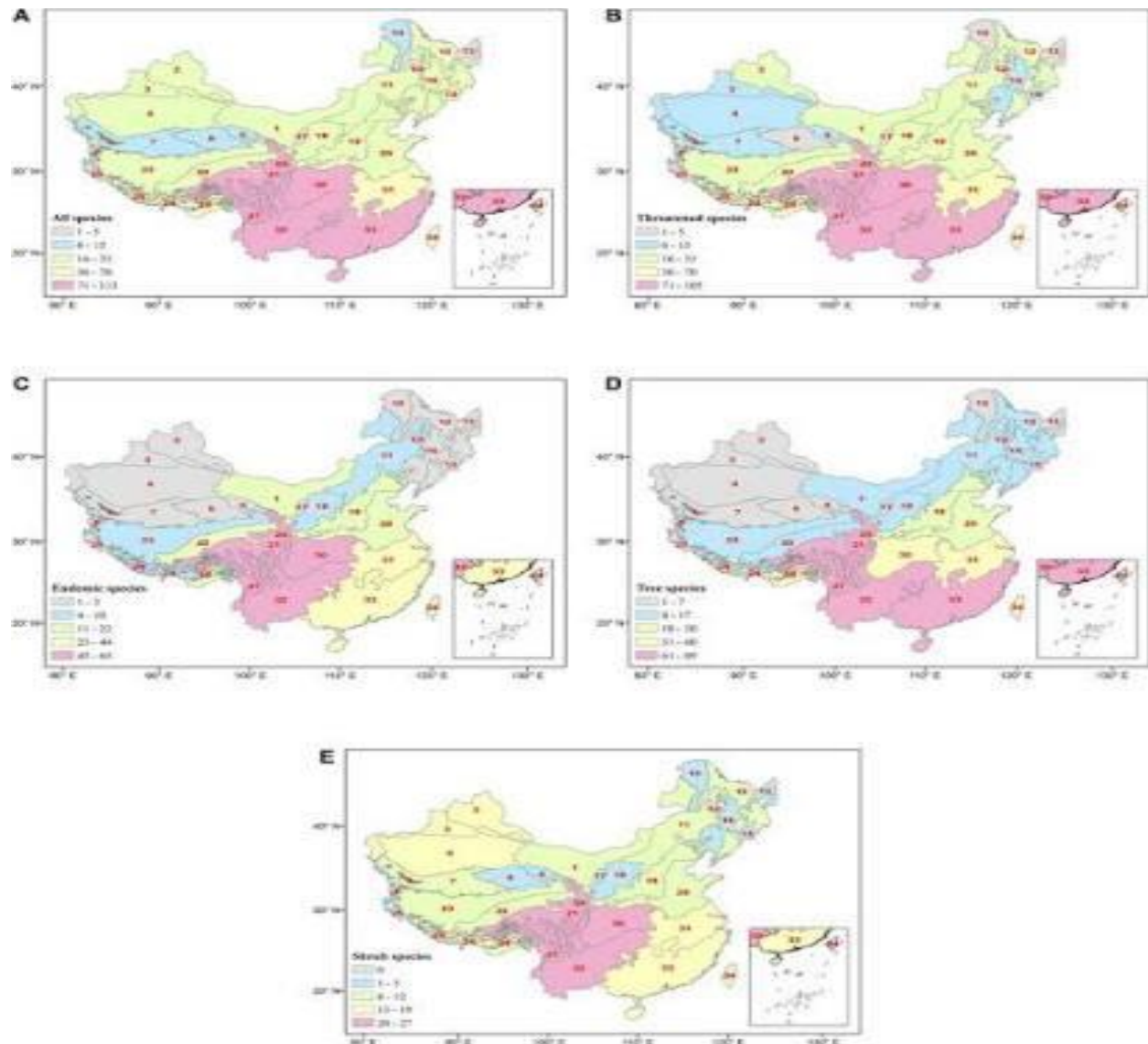


Fig 5.2 Diversity and Abundance of Gymnosperm Species

Gymnosperm diversity study shows forest environments that have adequate moisture, less anthropogenic disturbance, and more elevation have greater diversity of gymnosperm species. In forest environments that have experienced substantial changes in land use, deforestation, and climate change, gymnosperm species show reduced abundance.

The study confirms the importance of preserving diverse populations of gymnosperm species because ecologically, gymnosperm populations that are composed of varying species increase the resistance and stability of forest ecosystems amidst changes in the environment.

Relationship Between Climate Variables and Species Distribution
Climate variable analysis finds a strong association between climate and the distribution

of gymnosperms. The climate variables and the environmental factors that affect the occurrence and environmental suitability of species include temperature and precipitation.

Table 5.3: Relationship Between Climate Variables and Gymnosperm Distribution

Climate Variable	Correlation Value (r)	Influence Level
Temperature	-0.72	High Negative Effect
Precipitation	0.68	Positive Effect
Elevation	0.75	Strong Influence
Humidity	0.52	Moderate Influence

Increased temperature caused an adverse effect on species endemic to cold mountain environments, including most gymnosperms grown at high elevations. Changes in moisture

availability impact species' ability to grow and regenerate through the effect of moisture on the physiological processes.

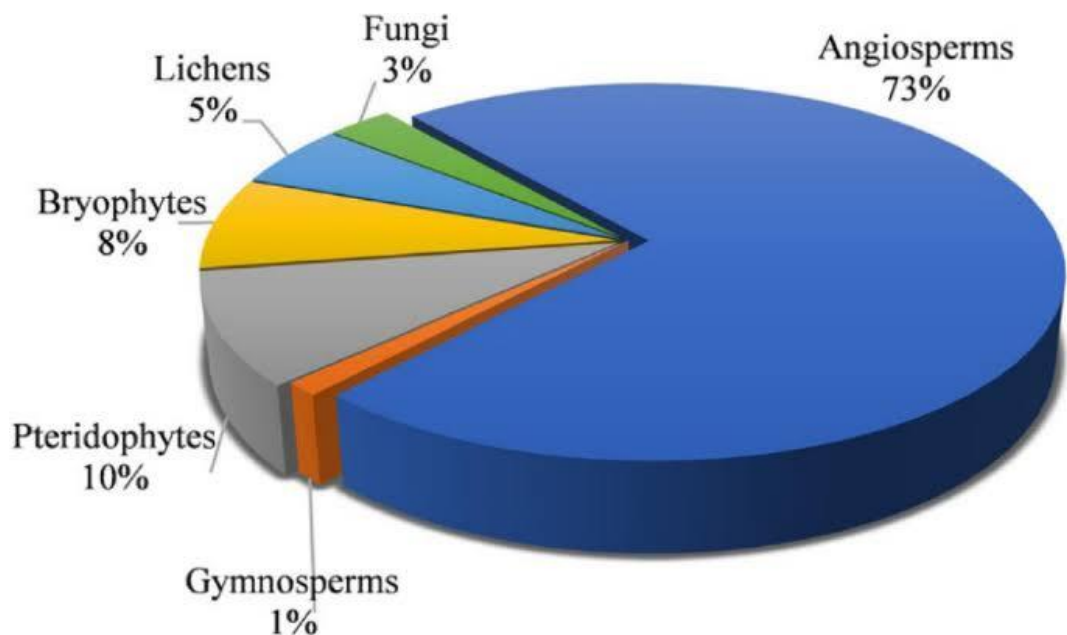


Fig 5.3 Relationship Between Climate Variables and Species Distribution

From the patterns of species occurrence, it is evident that different types of gymnosperms have varying preferences for climate. Most high elevation species are more associated with low temperature, whereas species of lower elevations are adapted to a higher temperature. The results of the analyses provide evidence that climate invariably accounts for a significant part of the explanation to the variation in the distribution of species. Temperature and

precipitation related variables indicate important factors in the determination of habitat suitability and abundance of the species.

Changes in Elevational Distribution Patterns
Patterns of vertical distribution demonstrate how climate change is shifting the elevation ranges of gymnosperm species in the Hazara Region. Higher temperatures are forcing those species toward habitat ranges of decreasing temperature.

Table 5.4: Observed Elevational Shifts of Gymnosperm Species

Species	Historical Elevation Range (m)	Current Elevation Range (m)	Shift (m)
<i>Cedrus deodara</i>	1200–2800	1400–3000	+200
<i>Pinus wallichiana</i>	1600–3200	1800–3400	+200
<i>Abies pindrow</i>	2000–3400	2200–3600	+200
<i>Picea smithiana</i>	1900–3200	2100–3400	+200

Those trends show the possible range shifts of some gymnosperm species towards higher elevations. This is an ecologically induced vertical shift due to climate change in response to changes in optimal temperature and moisture ranges.

These changes in elevation ranges may predict changes in the composition of forests by allowing some species to become dominant, while other species may shrink in distribution range.

Predicted Future Distribution Under Climate Change Scenarios

Species Distribution Modelling (SDM) predictions demonstrate the possible future habitat distribution of gymnosperm species within shifting future climate scenarios. From these models, it has been shown that many important gymnosperm species will undergo significant shifts in their current ranges.

With respect to future climate scenarios with increasing temperatures, many cold-adapted species are expected to lose available habitat in lower elevated regions. As temperature increases, the existing habitat of several species will become uninhabitable.

Table 5.5: Predicted Habitat Suitability Under Future Climate Conditions

Species	Current Suitable Habitat (%)	Future Suitable Habitat (%)	Change (%)
<i>Cedrus deodara</i>	78	65	-13
<i>Pinus wallichiana</i>	82	70	-12
<i>Abies pindrow</i>	75	55	-20
<i>Picea smithiana</i>	70	52	-18

Other species with greater temperature adaptability may even expand their historically stable ranges into newly available climate area. Such distribution shifts are dependent on the adaptability, dispersal, and habitat availability of the species.

Maps predicting the distribution of these species show potential new conservation areas, as many species may use these predicted areas as future refugia.

Potential Habitat Loss and Expansion Areas

The results of the habitat suitability analysis identify areas which are projected to undergo either climate change induced habitat loss or

gain. Areas of projected decrease in both temperature and moisture availability may experience loss of Gymnosperm habitats. Areas with higher elevation will have cooler temperatures which is ideal for many climate sensitive species and therefore will act as safety zones. However competition for available resources will increase over time putting limits on how sustainable the habitats will be. Whereas some area may experience expansion of their habitats for certain Gymnosperm species as a result of climate change. These changes are likely to impact how forests are structured and interact with other species.

Table 5.6: Predicted Habitat Change Areas

Habitat Category	Area Percentage (%)	Expected Change
Habitat Loss Zone	25%	Declining suitability
Stable Habitat Zone	50%	No major change
Expansion Zone	25%	Increasing suitability

Understanding where loss and gains in habitat occur will help with making better informed recommendations for management of forests and will help with the goals of conservation efforts.

Statistical Results and Model Outputs

Statistical analysis and modeling illustrate associations between environmental factors and gymnosperm distributions. Results show particularly strong effects for temperature, precipitation, and elevation. They also show that climatic factors are the main determinants of species occurrence.

Table 5.7: Species Distribution Model Performance

Species	Model Accuracy (AUC Value)	Prediction Accuracy
<i>Cedrus deodara</i>	0.89	Excellent
<i>Pinus wallichiana</i>	0.86	Very Good
<i>Abies pindrow</i>	0.91	Excellent
<i>Picea smithiana</i>	0.87	Very Good

The results from regression and correlation analyses illustrate diverse types of associations of climate variables and species distributions. Those species with low climatic tolerance demonstrate stronger response to environmental changes than those species with high adaptability.

The results of the Species Distribution Model show good predictability, and therefore, have high confidence level in estimating current and future habitat conditions. The model illustrates the main drivers of species distribution along with areas that require conservation effort.

CONCLUSION

RECOMMENDATIONS

The aim of the study is on the impacts of climate change on the changing distribution of gymnosperm species in the Hazara Region. The result indicates changing climate has a negative impact on the distribution, the number of individuals, and the quality of the habitat of key gymnosperm species found in the mountain forests.



This study examines the impacts of climate change on the distribution of gymnosperm species and describes how changes in precipitation, temperature, and elevation will affect the growth and survival of species. More specifically, a species that can tolerate a broader range of temperatures and other environmental variables will be better adapted to changing conditions; a species that is adapted to cooler environments will be more negatively impacted by climate change.

The study reveals that gymnosperm species, though they exist in the Hazara Region, do not uniformly distribute. Their presence is related to distinct elevations and qualities of the regional climates. High elevation habitats contain climate-sensitive species, while low elevation habitats are more stressed by the changing regional climates.

This study also suggests that changing climates may result in shifting elevational ranges of gymnosperm species. As climate conditions change, some species will be more negatively impacted and may have to move to upper

elevations to find more suitable habitats. Conversely, the upper elevations may be more stressed due to the lack of available habitats. Species Distribution Modelling (SDM) and GIS-based analysis permit the identification of current and projected habitat suitability. Our models show some gymnosperm species losing habitat in the future, while others may experience stable or increasing suitable habitats. These impacts could change forest structure and change how ecosystems function.

Conclusion

Climate change impacts the ecological patterns and species ranges of gymnosperms in the Hazara Region. Climatic factors influence gymnosperm species' habitat and range.

Gymnosperms are vital parts of the ecosystems of the Himalayas because of the ecosystems' services of carbon sequestration and storage, soil stability, biodiversity and biomass production, and regulation of the climate. However, the dependence of gymnosperms on certain conditions makes them very susceptible to changes in climate that may be rapid.

Increased temperatures and changed precipitation patterns lead to shifts in the ranges of species, though especially in the case of changing climates on different elevations. Some species may get habitats that are too small due to unsuitable climates and may thus suffer habitat loss, while other species may colonize habitats that have become too large. These may lead to changes in the stability of ecosystems and their biodiversity.

Analysis of climate driven changes of vegetation is best achieved by GIS, remote sensing and Species Distribution Modeling. With their help, the most vulnerable species may be identified, changes in the distributions of species may be predicted, and such changes may be planned to be incorporated into adequate and informed conservation practices.

Climate change impacts gymnosperm diversity in the Hazara Region. Measures of sustainably managing the forests and ecological systems of the mountains must be employed. In addition, climate change adaptation strategies and

ecosystems monitoring must be employed to protect gymnosperm resources.

Recommendations for Future Research

Future studies should concentrate on assessing long-term gymnosperm population trends to understand how species may redistribute, how they regenerate, and how ecosystems may respond to changing climates. Field studies that allow for continuous observation may capture more interesting and valuable data on the impacts of changing climates on plant growth.

Subsequent studies should focus on a greater portion of Pakistan and include other forest systems to understand how the climate affects different regions of Pakistan. Studying beyond the Hazara Region helps understand the impacts beyond the region on Himalayan gymnosperm species.

More accurate predictions of future habitat suitability can be attained through more advanced Species Distribution Models that consider multiple climate scenarios, land-use changes, and ecological interactions. The use of remote sensing coupled with field observations can help improve Vegetation monitoring.

Studies that investigate the genetic variability of gymnosperm species are important to be able to predict their species-level adaptability to changing climatic conditions. Identifying species-level adaptability can help predict which populations of gymnosperm species will be the most vulnerable to the challenges of a changing climate, and which may even survive the challenges.

Forest habitats that support gymnosperm species should be the focal point of all conservation efforts. The creation of new protected areas, restoration of previously destroyed habitats, and maintaining an active role in the management of forested areas will sustain all forms of ecosystem life.

Lastly, adaptive strategies to the climate challenges faced by gymnosperm forests are best when devised by ecologists and forest managers in collaboration with experts on the local climate.

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