

# Wildlife Diversity, Plant Ecology, And Climate Interactions in Kishtwar High Altitude National Park (Khanp), Jammu and Kashmir" India

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**Abstract-** Kishtwar High Altitude National Park, located in the western Himalayas of Jammu & Kashmir, represents a critical biodiversity hotspot characterized by unique wildlife diversity, complex plant communities, and distinct climatic regimes. This review synthesizes current knowledge on the park's ecological structure, with a focus on faunal and floral diversity, altitudinal zonation, and climate-vegetation-wildlife interactions. The park harbors iconic Himalayan species such as the snow leopard (*Panthera uncia*), Himalayan musk deer (*Moschus chrysogaster*), and a range of endemic alpine flora. Vegetation patterns are tightly governed by elevation and climatic variability, forming well-defined bioclimatic zones from temperate forests to alpine meadows. Moreover, the review explores the impact of climate change on ecological balance, species distribution, and conservation priorities in this fragile ecosystem. A need for integrated monitoring, climate-resilient conservation policies, and community engagement is emphasized to ensure the long-term ecological stability of Kishtwar National Park.

**Keywords:** Alpine Ecosystems, Altitudinal Zonation, Biodiversity Conservation, Climate Change Impact, Climate Interactions, Endemic Species, Kishtwar High Altitude National Park, Plant Ecology, Wildlife Diversity, Western Himalayas.

## 1. INTRODUCTION

### A. Location and Ecological Importance of Kishtwar High Altitude National Park

Kishtwar High Altitude National Park (KHANP), located in the Northern-Eastern part of the Kishtwar district in the Union Territory of Jammu and Kashmir, India, lies between 33°20' to 34°15' N latitude and 75°25' to 76°10' E longitude, encompassing an area of approximately 2,190.50

km<sup>2</sup> (Wani *et al.*, 2020). Established in 1981, the park forms a crucial part of the Greater Himalayan biodiversity corridor and is recognized for its unique high-altitude ecosystems, ranging from 1,700 to over 6,000 meters above sea level.

KHANP is characterized by complex topography, glaciated valleys, alpine meadows, snow-covered peaks, and temperate coniferous forests. It supports a diverse range of flora and fauna, including several endemic, threatened, and keystone species such as the Snow Leopard (*Panthera uncia*), Hangul (*Cervus hanglu*), Himalayan Musk Deer (*Moschus leucogaster*), and Western Tragopan (*Tragopan melanocephalus*) (Raza *et al.*, 2019; Bhat *et al.*, 2023). Its positioning at the transition between the Western Himalaya and Trans-Himalaya makes it ecologically significant, as it serves as a critical biodiversity refuge and migration corridor in the face of climate variability.

Moreover, KHANP plays a pivotal role in sustaining hydrological regimes, regulating microclimates, and supporting pastoral and agro-pastoral communities dependent on ecosystem services for grazing, medicinal plants, and forest products (Dar *et al.*, 2018). Given its rich biodiversity and ecosystem functions, the park has been prioritized for conservation under various national and international frameworks, including the Biodiversity Hotspot of the Himalayas.

### B. Objective and scope of the review

Despite its ecological significance, there exists fragmented scientific knowledge regarding the interactions among wildlife diversity, vegetation dynamics, and changing climate patterns in

KHANP. This review aims to synthesize existing literature and field-based observations to understand:

- I. The diversity and distribution patterns of wildlife species, including mammals, birds, and herpetofauna.
- II. Plant ecological characteristics, including floristic composition, vegetation zonation, and phenological responses to altitudinal gradients.
- III. Climate change trends and their impacts, particularly on species migration, habitat fragmentation, and ecosystem resilience.

The scope of this review is multidisciplinary, integrating concepts from wildlife biology, plant ecology, climate science, and conservation management. It seeks to identify knowledge gaps, highlight vulnerable taxa and ecosystems, and suggest adaptive conservation strategies. Emphasis is also placed on traditional ecological knowledge of local communities, which is crucial for participatory management.

This work aspires to support policy decisions and research initiatives under frameworks such as the National Biodiversity Action Plan (NBAP) and Himalayan Climate Resilience Program (HCRP), particularly in the context of sustainable development and climate adaptation in Himalayan protected areas.

## 2. PHYSICAL AND CLIMATIC OVERVIEW

### A. Geography, Topography and Elevation

Kishtwar High Altitude National Park (KHANP), located in the Kishtwar district of Jammu and Kashmir, represents a critical section of the Western Himalayan biogeographic zone. It spans an area of approximately 2,190.50 km<sup>2</sup>, and lies between 33°18' to 34°12' N latitude and 75°55' to 76°48' E longitude. The park is bordered by the River Runney in the east, Chenab river valleys, the Zanskar Range in the north, and Dachhan Valley to the south and River marau and human habitation.

KHANP features a diverse topography, characterized by high peaks (including Sickle Moon Peak, 6,574 m), Glacial valleys, Deep gorges, and Undulating alpine meadows (Rodgers *et al.*, 2000;

Wani *et al.*, 2022). Elevation in the park ranges from 1,700 m to over 6,000 m, creating sharp altitudinal gradients that give rise to a mosaic of ecosystems from temperate broadleaf forests in the lower ranges to permanent snow and ice in the uppermost zones.

The region is drained by glacial-fed tributaries like the Kibar and Nanth Nallahs, which merge into the Chenab River, contributing to the Indus basin (Biodiversity Strategy and Action Plan for Jammu & Kashmir, 2002).

### B. Climatic Conditions (Temperature, Precipitation, Seasonality)

The climate of KHANP is typical of cold temperate to alpine regimes, highly influenced by elevation, latitude, and the surrounding orography of the Greater Himalayas.

- Temperature: The lower zones (1,700–2,500 m) experience moderate summers (15°C to 25°C) and cold winters, while higher reaches often record sub-zero temperatures year-round. Above 3,500 m, the mean winter temperature frequently drops below –15°C, and the growing season is limited to 3–4 months (Singh *et al.*, 2010; Pandit *et al.*, 2014).
- Precipitation: Annual precipitation ranges between 800 mm and 1,500 mm, with snowfall dominating above 3,000 m. The region experiences a bimodal precipitation regime—snow during winter (December–March), and rainfall from the southwest monsoon (July–September). This moisture regime shapes vegetation phenology, biomass production, and animal migration (Shrestha *et al.*, 2012; Wani *et al.*, 2022).
- Seasonality: The year is divided into distinct spring (April–May), summer (June–August), autumn (September–October), and winter (November–March) phases. This seasonal variation strongly affects wildlife behavior, floral blooming periods, and availability of forage for herbivores such as the Himalayan musk deer and markhor.

### C. Glacial and Snow Cover Dynamics

KHANP contains several small and medium-sized glaciers, such as the Bramhagiri and Naag Pahalgam glaciers, which act as headwaters of key tributaries

in the Chenab River system. These glaciers, like others across the Himalayas, have shown consistent retreat trends over recent decades, attributed to regional warming and changes in snowfall patterns (Bolch *et al.*, 2012; Yao *et al.*, 2012).

- Snow cover varies with elevation and season, influencing ground insulation, soil moisture, and plant productivity. Snow persistence at elevations above 3,500 m delays the start of the growing season and restricts wildlife access to alpine pastures (Singh *et al.*, 2010; Sharma *et al.*, 2020).
- Glacial meltwater is vital for sustaining alpine streams, wetlands, and spruce-fir-birch forest ecosystems during the dry summer months. Alterations in glacial volume and snowmelt timing may impact downstream hydrology and ecological interactions (Immerzeel *et al.*, 2010; Bajracharya *et al.*, 2011).

These cryospheric processes, in conjunction with temperature and precipitation variability, determine habitat availability, biodiversity patterns, and the resilience of ecological communities in KHANP.

### 3. VEGETATION AND PLANT ECOLOGY

The Kishtwar High Altitude National Park (KHANP), located in the northeastern part of Jammu and Kashmir, lies within the Greater Himalayas and encompasses a remarkable diversity of vegetation types, shaped by elevation, climate, topography, and edaphic conditions. The park spans altitudinal gradients from 1,700 m to over 4,800 m, creating distinct vegetation zones and supporting unique plant communities that are ecologically and economically significant.

#### A. Vegetation Zonation by Altitude

The park's vegetation can be categorized into four principal altitudinal zones (Rana *et al.*, 2002; Singh & Rawat, 2012):

- I. Sub-tropical and Temperate Zone (1,700–2,500 m)
  - Dominated by broad-leaved species like *Quercus leucotrichophora*, *Rhododendron arboreum*, *Aesculus indica*, and *Juglans regia*.

- This zone features mixed deciduous forests interspersed with chir pine (*Pinus roxburghii*) in drier slopes.

- II. Temperate Coniferous Forest Zone (2,500–3,500 m)

- Includes dense stands of *Abies pindrow*, *Picea smithiana*, *Cedrus deodara*, and *Pinus wallichiana*.
- Understory species include *Berberis spp.*, *Rubus spp.*, and several herbaceous taxa.
- High biodiversity in this zone provides critical habitat for many large mammals.

- III. Sub-alpine Zone (3,500–4,000 m)

- Characterized by krummholz formations and scattered stunted trees like *Betula utilis* and *Rhododendron campanulatum*.
- The understory consists of alpine meadows, rich in grasses (*Poa*, *Festuca*) and forbs (*Primula*, *Potentilla*, *Anemone*).

- IV. Alpine Zone (>4,000 m)

- Treeless, dominated by alpine pastures and herbaceous species adapted to cold, wind-exposed environments.
- Prominent flora include *Saxifraga spp.*, *Saussurea spp.*, and medicinal plants like *Aconitum heterophyllum* and *Picrorhiza kurroa*.

#### B. Dominant Plant Species and Plant Communities

The floristic composition varies with altitude and exposure. It harbors more than 500 plant species. Some prominent communities include:

- Mixed Coniferous Forests: *Abies*, *Picea*, and *Cedrus* species dominate, interspersed with *Acer caesium* and *Betula utilis*.
- Alpine Meadows (Bogyals): These are high-altitude grasslands with species like *Primula*, *Gentiana*, and *Polygonum*. Rich in summer bloom, they are critical grazing grounds for wild herbivores.
- Shrublands: Dominated by *Rhododendron anthopogon*, *Lonicera spp.*, and *Salix spp.*, particularly in transitional and subalpine zones.

C. Endemic and Medicinal Plant Species

KHANP hosts several endemic and medicinal plant species due to its climatic isolation and topographical complexity:

I. Endemic Plants:

- *Meconopsis latifolia*, *Rheum webbianum*, *Podophyllum hexandrum*, and *Saussurea costus*.
- Many are alpine specialists with narrow ecological niches.

II. Medicinal Plants:

- *Aconitum heterophyllum*, *Picrorhiza kurroa*, *Arnebia benthamii*, *Nardostachys jatamansi*, and *Dactylorhiza hatagirea*.
- Used in traditional Amchi, Unani, and Ayurvedic medicine; some are endangered due to overharvesting.

C. Ecological Roles of Vegetation Types

Vegetation in KHANP plays multifaceted ecological roles:

- Habitat and Food Source: Supports flagship species like the Himalayan brown bear, snow leopard, musk deer, and various pheasants by providing cover and forage.
- Climate Regulation: Forests regulate local microclimates, conserve soil moisture, and reduce erosion.
- Carbon Sequestration: Subalpine and alpine forests store significant carbon in biomass and soil, contributing to regional climate buffering.
- Water Regulation: Alpine meadows and forests act as watersheds for the Chenab River, influencing hydrological dynamics and water availability downstream.
- Pollination and Biodiversity Support: Alpine flora supports insect pollinators (e.g., bumblebees) crucial for maintaining plant reproductive cycles in fragile ecosystems.

Table 1: Vegetation Zonation and Dominant Species in KHANP

Altitudinal Zone	Elevation Range (m)	Vegetation Type	Dominant Species	Remarks
Sub-tropical to Lower Temperate	1,700 – 2,500	Mixed broad-leaved forests	<i>Quercus leucotrichophora</i> , <i>Rhododendron arboreum</i> , <i>Aesculus indica</i> , <i>Juglans regia</i> , <i>Pinus roxburghii</i>	Found on warmer southern slopes; subject to anthropogenic pressure
Temperate Coniferous Forest	2,500 – 3,500	Dense coniferous forests	<i>Abies pindrow</i> , <i>Picea smithiana</i> , <i>Cedrus deodara</i> , <i>Pinus wallichiana</i>	Biodiversity-rich; critical for large mammals like Himalayan black bear
Sub-alpine Zone	3,500 – 4,000	Krummholz, Birch-Rhododendron scrub	<i>Betula utilis</i> , <i>Rhododendron campanulatum</i> , <i>Berberis spp.</i> , <i>Potentilla spp.</i> , <i>Anemone spp.</i>	Transition zone; supports seasonal grazing and rare alpine flora
Alpine Zone	>4,000	Alpine meadows and pastures	<i>Saxifraga spp.</i> , <i>Saussurea spp.</i> , <i>Meconopsis aculeata</i> , <i>Aconitum heterophyllum</i> , <i>Picrorhiza kurroa</i>	Treeless zone with high medicinal plant diversity; vulnerable to climate change

4. FAUNAL DIVERSITY

The Kishtwar High Altitude National Park (KHANP), established in 1981 and spanning over 2,190.5 km<sup>2</sup>, is a vital repository of biodiversity in the northwestern Himalayas. The park's altitudinal variation (1,700 to 6,000 m) supports diverse ecological zones, which in turn sustain rich and varied faunal communities.

A. Fauna Richness: Mammals, Birds, Reptiles, and Insects

KHANP harbors a diverse assemblage of fauna. Over 50 species of mammals, approximately 130 bird species, several reptiles and amphibians, and hundreds of insect taxa have been documented in the region (Sathyakumar, 1994; Wani et al., 2021).

- **Mammals:** Notable species include the Himalayan musk deer (*Moschus leucogaster*), Himalayan brown bear (*Ursus arctos*), Asiatic black bear (*Ursus thibetanus*), Himalayan tahr (*Hemitragus jemlahicus*), serow (*Capricornis thar*), goral (*Naemorhedus goral*), and leopard (*Panthera pardus*).
- **Birds:** Avifaunal diversity includes the monal pheasant (*Lophophorus impejanus*), koklass pheasant (*Pucrasia macrolopha*), bearded vulture (*Gypaetus barbatus*), and various high-altitude passerines and raptors.
- **Reptiles and Amphibians:** Limited but notable presence of cold-adapted species like *Agama tuberculata* and *Bufo himalayanus* is observed.
- **Insects:** Pollinator diversity is represented by multiple species of bees (*Apis spp.*), butterflies (e.g., *Papilio spp.*, *Pieris spp.*), and beetles, which play a crucial role in ecosystem functioning.

*B. Flagship and Endangered Species*

Several flagship and IUCN Red Listed species are found in KHANP:

- **Snow leopard (*Panthera uncia*) – Vulnerable:** A top predator and flagship species representing alpine conservation concerns.
- **Asiatic black bear (*Ursus thibetanus*) – Vulnerable:** A keystone species in mid-altitude forests.
- **Himalayan musk deer (*Moschus leucogaster*) – Endangered:** Hunted for musk, its presence indicates high-altitude forest health.
- **Western tragopan (*Tragopan melanocephalus*) – Vulnerable:** A globally threatened pheasant found in dense forests.

These species not only symbolize conservation values but also serve as bio-indicators of ecosystem

health (Schaller, 1977; Sathyakumar & Bhatnagar, 2002).

*C. Species Distribution by Habitat and Altitude*

Species in KHANP exhibit clear altitudinal zonation:

- **Lower zones (1,700–2,500 m):** Dominated by temperate broadleaf forests, inhabited by leopards, black bears, and pheasants.
- **Mid-altitude zones (2,500–3,500 m):** Characterized by coniferous forests and sub-alpine meadows supporting musk deer, serow, monal, and tragopan.
- **High alpine zones (>3,500 m):** Open alpine grasslands and scree slopes provide habitat to snow leopards, Himalayan tahr, and blue sheep (*Pseudois nayaur*).

This vertical stratification is driven by climatic gradients, vegetation shifts, and anthropogenic pressures (Kala & Mathur, 2002; Singh et al., 2020).

*D. Seasonal Movements and Migratory Species*

Wildlife species in KHANP exhibit distinct seasonal migrations and elevational shifts:

- **Snow leopard and blue sheep** migrate to lower elevations during winter due to heavy snowfall at higher altitudes.
- **Himalayan tahr and musk deer** exhibit altitudinal migration for forage availability.
- **Birds**, including warblers, flycatchers, and raptors, undertake seasonal movements and partial migrations from surrounding temperate zones.

Climate plays a pivotal role in influencing these migrations, impacting breeding, feeding, and shelter availability (Lovari et al., 2009; Singh et al., 2020).

Table 2: Faunal diversity of KNHAP

Faunal Group	Species Found	Notable/Endangered Species	Habitat/Altitude Range	Remarks
Mammals	~50 species	Snow Leopard ( <i>Panthera uncia</i> ), Himalayan Brown Bear ( <i>Ursus arctos isabellinus</i> ), Asiatic Black Bear ( <i>Ursus thibetanus</i> ), Hangul ( <i>Cervus elaphus hanglu</i> ), Musk Deer	1,700 – 4,800 m	Rich diversity due to vertical zonation; many species are IUCN-listed

Faunal Group	Species Found	Notable/Endangered Species	Habitat/Altitude Range	Remarks
		( <i>Moschus spp.</i> ), Himalayan Tahr ( <i>Hemitragus jemlahicus</i> )		
Birds	~150 species	Monal Pheasant ( <i>Lophophorus impejanus</i> ), Koklass Pheasant ( <i>Pucrasia macrolopha</i> ), Bearded Vulture ( <i>Gypaetus barbatus</i> ), Himalayan Griffon	Across all altitudes, from forest zones to alpine meadows	Park is an important bird area (IBA)
Reptiles	Limited diversity due to cold climate	Himalayan Pit Viper ( <i>Gloydius himalayanus</i> )	Lower altitude forested areas	Reptiles are less common due to high elevation and low temperatures
Amphibians	Scant data; very few species reported	-	Moist forest floors, near streams	Requires further study
Insects (Lepidoptera, Beetles, etc.)	Numerous species	Several endemic and pollinator species	Meadows, subalpine forests, riparian zones	Important for pollination and ecosystem functioning
Aquatic Fauna	Cold-water fish (e.g., <i>Schizothorax spp.</i> )	-	River Chenab and alpine lakes	Sensitive to temperature and glacial melt patterns

### 5. CLIMATE AND BIODIVERSITY INTERACTIONS IN KHANP

The Kishtwar High Altitude National Park (KHANP), exhibits complex and sensitive interactions between climate and biodiversity due to its rugged terrain, high altitudinal gradient (1,700 m to over 6,000 m), and alpine-subalpine ecosystems. These interactions critically influence vegetation patterns, faunal distributions, phenology, and ecological dynamics.

#### A. Climatic Profile of KHANP

KHANP spans elevations from ~1,700 m to over 4,800 m, resulting in diverse microclimatic regimes:

- **Temperature:** Mean annual temperatures range from sub-zero in alpine areas to ~15°C in the lower valleys. Winters are severe with heavy snowfall above 2,500 m.
- **Precipitation:** Receives 1,000–1,500 mm annually, mostly as snowfall in upper reaches and rain in lower zones. The southwest monsoon is weak; much of the precipitation is orographic.
- **Seasonality:** The area experiences distinct seasons—long winters (Nov–April), short

spring (May), brief summers (June–August), and autumn (September–October).

#### B. Influence on Flora

Climatic factors strongly influence vegetation composition, distribution, and phenology:

##### I. Altitudinal Vegetation Zonation

- Cooler temperatures and shorter growing seasons at higher altitudes confine tree growth, giving way to alpine meadows and herbaceous flora.
- Snow cover affects soil temperature, plant dormancy, and germination timing.

##### II. Phenological Responses

- Many alpine species (e.g., *Primula*, *Meconopsis*, *Anaphalis*) exhibit compressed life cycles and flower synchronously during a short summer growing window.

##### III. Species Migration and Range Shifts

- Climate warming trends (~0.4–0.6°C per decade) are shifting plant communities upward (Ranjitkar et al., 2014).
- Cold-adapted species like *Saussurea obvallata* face habitat constriction due to upward competition.

#### IV. Impact on Medicinal and Endemic Plants

- Temperature extremes and unpredictable snowmelt alter the availability and productivity of threatened medicinal plants such as *Aconitum heterophyllum*, *Picrorhiza kurroa*, and *Dactylorhiza hatagirea*.

#### B. Influence on Fauna

Climate directly and indirectly impacts the distribution, survival, and behavior of wildlife in KHANP:

##### I. Habitat Compression and Altitudinal Shifts

- Species such as the Himalayan musk deer, snow leopard, and Himalayan tahr are increasingly moving to higher altitudes due to rising temperatures and shrinking snow cover.

##### II. Trophic Disruptions

- Early plant blooming can mismatch herbivore needs; similarly, insect emergence may not align with the breeding periods of insectivorous birds like snow partridges and pheasants.

##### III. Snow Cover and Survival

- Snow depth affects foraging access and predator-prey interactions. For instance, deep snow restricts ungulate movement while aiding ambush predators like the snow leopard.

##### IV. Migration and Seasonal Movements

- Certain avian species such as Himalayan monal and koklass pheasant show seasonal altitudinal migrations depending on snowline and temperature variations.

#### C. Threats from Climate Change

Climate change poses escalating threats to the ecological integrity of KHANP:

##### I. Habitat Shifts:

- Alpine meadows are moving upward, encroaching upon permanent snow and rock zones, while lower elevation species invade subalpine habitats.
- Forest composition is changing; species like *Cedrus deodara* and *Pinus roxburghii* are expanding upwards, often outcompeting native flora.

##### II. Glacial Retreat:

- The receding of small glaciers and permanent snowfields is reducing water availability in alpine pastures, critical for both wild ungulates and domestic livestock.
- Loss of snowfields can also impact species like snow leopard and Himalayan marmot, which rely on snow-covered areas for concealment and thermal regulation.

##### III. Extreme Weather Events:

- Increased frequency of cloudbursts, landslides, and erratic snowfall patterns disrupt breeding, feeding, and hibernation behaviors in fauna.
- High mortality of young and thermally sensitive species during unseasonal snow or temperature spikes.

##### IV. Ecosystem Disequilibrium:

- These changes can result in *trophic mismatches*, leading to reduced reproductive success and species survival, ultimately affecting overall biodiversity resilience.

## 6. CONSERVATION CHALLENGES AND MANAGEMENT STRATEGIES

#### A. Human–Wildlife Conflict and Habitat Degradation

- Extensive grazing pressure: Over 1,115 nomadic families with ~25,000 livestock, along with local villagers' livestock (~10,000 head), have grazing rights within the park, which can cause habitat degradation and resource competition.
- Illegal encroachment: Reports mention encroachment of forest land in Kishtwar—roughly 379.72 hectares—highlighting pressures on protected areas.
- Tourism-induced pollution: In nearby areas like Sinthan Top, skyrocketing tourist footfall has led to plastic pollution and damage to pristine landscapes, which could affect adjacent ecosystems if unchecked.

#### B. Role of Local Communities and Eco-Development

- Biodiversity Management Committees (BMCs): These facilitate community engagement in biodiversity management, blending traditional knowledge with contemporary conservation efforts.
- Eco-tourism opportunities: Surveys captured ~20 snow leopards, including a mother and cubs—this presents a strong foundation for responsible eco-tourism that can benefit local youth and foster conservation awareness.

#### C. Protected Area Management and Policy Framework

- Eco-Sensitive Zone (ESZ) Master Plan: Authorities are formulating a zonal master plan for the 547.09 km<sup>2</sup> ESZ to regulate development while balancing environmental integrity.
- CAMPA-backed mitigation action plan: This includes habitat improvement, boundary delineation, wildlife protection, compensatory afforestation, and biodiversity conservation, all scheduled for execution over a five-year timeline.

#### D. Habitat Improvement & Afforestation (CAMPA Initiative)

- Mitigation Action Plan: Funded through CAMPA via hydropower project funds, this five-year Action Plan includes boundary demarcation, habitat restoration, wildlife protection, and eco-development interventions.

A DPR is under preparation by specialized institutions .

#### E. Biodiversity Monitoring & Wildlife Surveys

- Camera-trap monitoring: Confirmed sightings of snow leopards (including cubs) using camera traps in multiple areas (Renai, Padder, Kishtwar landscape) affirm breeding and a robust population baseline—critical for ongoing conservation & ecotourism planning .

#### F. Comprehensive Ecological Research

- Multi-faceted surveys: Projects led by the National Development Foundation and others encompass:
  - Mammal, bird, insect, aquatic and plant species occupancy/density surveys.
  - Human-wildlife conflict assessments, grazing impact studies, and GIS-based land-use mapping.
  - Climate change impact modeling, ecosystem service mapping, and disease monitoring.
  - Infrastructure needs, technological interventions, and DPR development for long-term conservation planning .
- Baseline studies on predators and prey: Field surveys, occupancy modeling, and community consultations are underway to map key large carnivores (e.g., snow leopard, brown bear), their prey bases, and socio-cultural dynamics .

#### G. Eco-tourism & Community Engagement

- Tourism for conservation and livelihood: Recognition of snow leopards in the region is being positioned as an opportunity for responsible eco-tourism, which can provide local youth with jobs as guides while raising conservation awareness .

### 7. KNOWLEDGE GAPS AND RESEARCH NEEDS

#### A. Lack of Baseline Ecological Data

The Kishtwar High-Altitude National Park (KHANP) suffers from paucity of foundational ecological datasets—such as species inventories, abundance metrics, and habitat mapping across taxa.

A recent conservation planning outline emphasizes the need for systematic surveys of fauna—including Hangul, snow leopard, musk deer, pheasants, insects, butterflies, flora and even aquatic biodiversity—as well as GIS mapping of land-use and ecosystem resources. This underscores the necessity of establishing robust baseline data across multiple ecological layers.

### B. *Species-Specific Ecological Studies*

While rudimentary documentation exists, in-depth ecological studies remain sporadic. KLHP's snow leopard population was recently assessed using spatial capture-recapture methods, revealing an estimated density of 0.50 individuals per 100 km<sup>2</sup>, along with relative abundance indices (RAI) for other mammals like the endangered Kashmir musk deer and marmots. This work marks an important start, but there are considerable gaps in understanding population dynamics, ecological behavior, and interspecific interactions—not just of mammals but of endangered or endemic plant species, birds, insects, and amphibians.

### C. *Importance of Long-Term Monitoring and Multidisciplinary Research*

One-off snapshots have limited value in isolating trends or predicting ecological responses under climate change. Longitudinal datasets linking biodiversity with climatic variables, hydrology, land-use, and human activities are vital. The observational framework needs to integrate disciplines—from wildlife ecology to climatology, hydrology, sociology (nomadic livelihoods), and ecosystem services—mirroring the comprehensive agenda outlined by conservation planners in the region

### D. *Integration of Remote Sensing and GIS in Ecological Monitoring*

Geospatial technologies are crucial for spatially extensive, repeatable, and scalable environmental monitoring. In the broader Hindu Kush Himalayan (HKH) region, remote sensing and GIS have been widely applied to track glacier retreat, land-use/land-cover change, disasters (e.g., landslides, floods), and forest degradation over time. Region-specific examples include land-cover change and prediction modeling for Wular Lake,

showing dramatic declines in forest (~40.8%) and other vegetative classes while impervious surfaces and agriculture expanded. Moreover, broader syntheses of remote sensing usage in ecosystem health assessment—though often conducted in temperate or grassland biomes—recommend standardizing indicators, combining field and remote-based measures, and developing unified monitoring frameworks.

## 8. CONCLUSION

Kishtwar High Altitude National Park (KHANP) embodies a remarkable ecological mosaic, shaped by sharp altitudinal gradients and climatic variability. Its rich biodiversity includes iconic species like the snow leopard, Himalayan musk deer, and a wide array of endemic flora adapted to extreme environments. These natural assets are, however, increasingly threatened by climate change, glacial retreat, habitat fragmentation, human-wildlife conflict, and anthropogenic pressures such as overgrazing and unregulated tourism. The upward migration of species, phenological mismatches, and shrinking alpine habitats highlight the park's ecological vulnerability in a rapidly warming Himalaya.

Safeguarding KHANP's ecological integrity demands an integrated conservation approach that is informed by both current climate science and local socio-ecological dynamics. Adaptive management strategies—backed by robust environmental monitoring, eco-sensitive zoning, and sustainable land use planning—must be institutionalized. Climate-resilient frameworks such as the CAMPA-funded mitigation plans and Environment Management Plans need implementation at scale, emphasizing habitat restoration, species protection, and ecosystem connectivity.

Long-term ecological research and systematic biodiversity monitoring are essential for understanding species responses to climate and anthropogenic stressors. Bridging scientific knowledge with traditional ecological wisdom through inclusive community engagement is equally crucial. Strengthening local stewardship via eco-tourism, Biodiversity Management Committees, and youth-led conservation initiatives can ensure that the park's natural wealth becomes a cornerstone for sustainable development. KHANP's future hinges

not only on policy and science, but on the active participation of the communities that have long coexisted with its wilderness.

To advance the scientific understanding and conservation potential of KHANP, there is dire need for:

- Launching systematic baseline surveys for flora, fauna (across all taxa), and ecosystem services;
- Carrying out species-level ecological studies, particularly on endangered/endemic flora and fauna;
- Establishing long-term, integrated monitoring programs that tie biodiversity trends to climate, hydrology, land-use, and human pressures;
- Leveraging remote sensing and GIS, including real-time sensor data and satellite imagery, to produce scalable, collaborative tools for ecosystem assessment and management.

These efforts will be foundational for evidence-based conservation planning and for evaluating how wildlife, plant communities, and climate interact in this ecologically sensitive region.

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