

Climate Change and Plant Biodiversity in the Mountain Ecosystems of Oman: A Concise Review

Sivamani Selvaraju*

Mechanical and Chemical Engineering Unit, Department of Engineering and Technology, University of Technology and Applied Sciences, Salalah, Oman.



Article History

Received: 06.09.2026

Accepted: 01.10.2026

Published: 25.10.2026

Corresponding Author:
Sivamani Selvaraju *

Abstract: The mountain ecosystems of Oman represent important centres of plant biodiversity within the arid Arabian Peninsula, supporting distinctive vegetation communities, geographically restricted species, and habitats maintained by complex interactions among elevation, precipitation, temperature, and atmospheric moisture. The Al Hajar Mountains of northern Oman and the Dhofar Mountains of southern Oman exhibit contrasting climatic regimes, making them particularly valuable for understanding the ecological consequences of climate change in arid and semi-arid mountain environments. This review critically examines the relationships between climatic variability, plant biodiversity, ecological vulnerability, and conservation priorities across these mountain systems. Particular attention is given to the montane juniper woodlands of the Al Hajar Mountains and the seasonally cloud-affected woodlands of Dhofar. Available evidence indicates that warming, water limitation, and altered moisture availability may threaten vegetation persistence, recruitment, and habitat suitability. However, climate-related pressures frequently interact with grazing, land-use change, habitat fragmentation, and other anthropogenic disturbances, complicating the attribution of observed vegetation changes to climate change alone. The review highlights differences between northern and southern mountain ecosystems, evaluates the strength of existing evidence, and identifies limitations associated with insufficient long-term monitoring, incomplete species distribution records, and limited integration of climate projections with ecological observations. Future conservation efforts should prioritize climate-sensitive habitats, systematic biodiversity monitoring, improved understanding of fog-vegetation interactions, and spatially explicit assessments of species vulnerability. Integrating ecological research with climate modelling and sustainable land management could strengthen biodiversity conservation and ecosystem resilience in Oman's mountain landscapes.

Keywords: Al Hajar Mountains; Dhofar Mountains; Endemic flora; Conservation.

Cite this Article

S. Selvaraju, (2026) Climate Change and Plant Biodiversity in the Mountain Ecosystems of Oman: A Concise Review *GRS Journal of Multidisciplinary Research and Studies*, Vol-3 (Iss-10). 60-65

Introduction

Mountain ecosystems occupy a distinctive position in global biodiversity conservation because they encompass pronounced environmental gradients over relatively short geographical distances. Variations in elevation, slope, aspect, soil properties, and atmospheric conditions generate heterogeneous habitats that support diverse plant communities, including species with narrow ecological tolerances and restricted geographical distributions. In arid and semi-arid regions, mountains are particularly important because relatively cool temperatures, localized precipitation, and favourable moisture conditions can sustain vegetation that would otherwise be unable to persist in surrounding lowland environments. Consequently, mountain landscapes frequently function as ecological refugia, centres of plant endemism, and reservoirs of genetic diversity [1,2].

Climate change presents a substantial challenge to these ecosystems. Rising temperatures, changing precipitation patterns,

prolonged droughts, and shifts in seasonal moisture availability may influence plant growth, regeneration, species distributions, and community composition. Mountain plants are especially sensitive to climatic changes because their distributions are often constrained by elevation-dependent environmental conditions. Under progressive warming, some species may shift towards higher elevations where suitable temperatures remain available. However, the extent of such movement depends on habitat connectivity, soil conditions, competition, dispersal capacity, and the availability of suitable environments. Species already occupying mountain summits or geographically isolated habitats may have limited opportunities for further migration [3].

The Sultanate of Oman provides an important geographical setting for investigating these relationships. Although much of the country experiences arid climatic conditions, its mountainous landscapes support comparatively heterogeneous vegetation assemblages influenced by regional climate, topography, and biogeographical history. Two major mountain systems are particularly significant:

The Al Hajar Mountains of northern Oman and the Dhofar Mountains of southern Oman. These regions differ considerably in their climatic characteristics, vegetation structure, and seasonal water availability, providing an opportunity to examine contrasting ecological responses to environmental change [2].

The Al Hajar Mountains, including Jabal Akhdar and Jabal Shams, contain high-elevation habitats supporting drought-adapted shrubs, scattered trees, and montane juniper woodlands. These vegetation communities experience substantial seasonal and altitudinal variation in temperature and moisture availability. Previous investigations of juniper woodland distribution and condition have raised concerns regarding population decline, limited regeneration, and the possible contribution of changing climatic conditions to long-term vegetation deterioration. Such findings are important because the persistence of high-elevation woody vegetation depends not only on the survival of established individuals but also on successful recruitment under increasingly variable environmental conditions [4,5].

In contrast, the Dhofar Mountains of southern Oman are strongly influenced by the southwest monsoon, locally known as the Khareef. During the summer monsoon season, moist maritime air produces cloud cover, fog, drizzle, and relatively cool conditions along portions of the south-facing mountain slopes. These conditions support seasonal grasslands, shrublands, and woodland communities that differ markedly from the predominantly arid vegetation of northern Oman. Fog interception and the associated redistribution of atmospheric moisture are particularly important ecological processes in these environments. Hildebrandt et al. (2006) demonstrated the significance of vegetation–moisture interactions in Dhofar's seasonal cloud forest, emphasizing the potential consequences of woodland degradation for local water availability [6].

Oman's mountain flora also has considerable conservation significance because of its phytogeographical diversity and the occurrence of endemic and regionally restricted plant species. Southern Oman, in particular, contains vegetation elements associated with the broader Arabian–African floristic region, while the northern mountains support distinctive high-elevation plant communities. Earlier national conservation assessments highlighted the importance of protecting threatened and geographically restricted plant taxa and their habitats. Nevertheless, biodiversity conservation in these regions faces multiple pressures, including grazing, settlement expansion, infrastructure development, tourism, and changing land-management practices. These pressures may intensify the effects of climatic stress, making it difficult to distinguish climate-driven ecological changes from those caused by direct human disturbance [7].

Despite the ecological importance of Oman's mountains, research remains uneven across regions, species groups, and environmental processes. Existing studies provide valuable information on floristic composition, juniper woodland condition, fog-dependent ecosystems, and plant conservation, but relatively few integrate long-term meteorological observations, vegetation monitoring, and future climate projections within a common analytical framework [1,3]. Moreover, evidence of climate-related ecological vulnerability should not automatically be interpreted as proof that climate change has caused every observed vegetation decline. Robust attribution requires consideration of grazing history, land-

use changes, demographic processes, and other potentially interacting drivers.

Against this background, the present review aims to critically synthesize current knowledge concerning climate change and plant biodiversity in the mountain ecosystems of Oman. Specifically, it examines the ecological characteristics and floristic significance of northern and southern mountain regions, evaluates the potential and documented effects of climatic variability on plant communities, identifies interacting environmental and anthropogenic pressures, and discusses conservation strategies and research priorities. By comparing the Al Hajar and Dhofar mountain systems, the review seeks to establish a geographically differentiated understanding of biodiversity vulnerability and highlight opportunities for climate-informed conservation and sustainable mountain ecosystem management.

Mountain Ecosystems and Plant Biodiversity in Oman

Al Hajar Mountains: High-elevation vegetation and ecological refugia

The Al Hajar Mountains contain some of the highest elevations in eastern Arabia and support plant communities that differ from those of the surrounding desert landscapes. Their ecological importance arises from altitudinal climatic gradients, heterogeneous terrain, and relatively sheltered habitats that facilitate the persistence of drought-sensitive and cold-tolerant species.

The montane juniper woodlands are among the most distinctive vegetation communities of northern Oman. Gardner and Fisher (1996) documented juniper occurrence predominantly at higher elevations, with substantial differences in tree condition between exposed slopes and shaded habitats. Their survey reported juniper on exposed slopes from approximately 2,100 m to the highest mountain summits, whereas sheltered north-facing slopes supported individuals at considerably lower elevations [4]. Woodland condition was generally poorer on exposed lower-altitude slopes, suggesting that local topography and moisture conditions influence population persistence.

Juniper taxonomy also requires attention. Earlier literature frequently classified the Omani population as *Juniperus excelsa* subsp. *polycarpus*, whereas subsequent molecular and ecological studies identify it as *Juniperus seravschanica*. Recognizing this taxonomic history is important when comparing older floristic surveys with recent conservation studies. The Al Hajar Mountains should not, however, be treated as a uniform ecological system. Differences in elevation, slope exposure, substrate, and human disturbance produce substantial variation in vegetation composition and structure. Mountain agricultural landscapes, rocky slopes, wadis, and juniper-dominated habitats may therefore exhibit different sensitivities to climatic change [5].

Dhofar Mountains: monsoon-influenced plant biodiversity

The Dhofar mountain system, including Jabal Qara, Jabal Al Qamar, and Jabal Samhan, supports vegetation influenced by the seasonal southwest monsoon. The Khareef produces cloud immersion, fog, drizzle, and reduced solar radiation across parts of the coastal mountain belt. These conditions allow relatively

moisture-dependent vegetation to persist within an otherwise arid regional environment [8].

The ecological importance of Dhofar is particularly evident in its seasonal cloud forests and woodlands. Hildebrandt and Eltahir (2006) investigated the hydrological functioning of a drought-deciduous woodland dominated by *Anogeissus* and demonstrated that tree canopies capture atmospheric cloud moisture. This additional water supply helps sustain vegetation during periods when conventional rainfall alone may be insufficient [6].

The relationship between vegetation and atmospheric moisture creates an important ecological feedback. Intact woodland canopies intercept cloud droplets, increasing water inputs beneath the

vegetation. Conversely, canopy loss reduces fog interception and may constrain natural woodland regeneration. This feedback suggests that vegetation degradation can influence local habitat conditions independently of, and in combination with, regional climate change. The southern mountains also possess high floristic conservation value. A national assessment published in 1998 reported that approximately 80% of the threatened plant taxa identified at that time occurred in southern Oman. This historical result demonstrates the importance of Dhofar for conservation planning, although the figures should not be interpreted as a current assessment without updated species inventories and threat evaluations [9].

Table 1. Ecological comparison of northern and southern mountain systems

Characteristic	Al Hajar Mountains	Dhofar Mountains
Geographic location	Northern Oman	Southern Oman
Dominant climatic influence	Arid mountain climate, episodic rainfall	Seasonal southwest monsoon and arid dry season
Moisture availability	Rainfall, localized runoff, soil moisture	Rainfall, drizzle, fog interception
Representative vegetation	Juniper woodlands, shrubs, mountain flora	Seasonal woodlands, grasslands, shrubs
Key ecological concern	Juniper regeneration and drought stress	Fog-dependent vegetation and canopy degradation
Principal human pressures	Grazing, tourism, land-use change	Grazing, woodland degradation, development
Research priority	Recruitment and altitudinal climate gradients	Fog hydrology and woodland recovery

Qualitative synthesis of published ecological studies; the Table 1 does not imply that all habitats within each mountain system experience identical conditions.

Climate Variability and Environmental Changes

Temperature and drought stress

Temperature influences mountain vegetation through its effects on evapotranspiration, soil moisture, photosynthesis, and plant physiological stress. Increasing temperatures can intensify atmospheric evaporative demand even where precipitation totals remain relatively stable. Consequently, the ecological consequences of warming depend on the interaction between temperature, water availability, and local habitat conditions. In the northern mountains, MacLaren (2016) examined the decline of *Juniperus seravschanica* and found that healthier trees and greater sapling occurrence were associated with cooler and wetter habitats. The study identified climate change as a major contributor to population deterioration and reported evidence consistent with an upward altitudinal shift in favourable habitat conditions. Topographically sheltered locations appeared to provide important climatic refugia. These findings provide comparatively strong evidence of climate-related ecological vulnerability in northern Oman. Nevertheless, the results primarily concern a particular tree species and should not automatically be generalized to all mountain plants. Species differ in rooting depth, drought tolerance, reproductive strategies, and physiological responses to environmental stress [5].

Precipitation variability and seasonal moisture

Precipitation is a major determinant of vegetation productivity and recruitment in arid mountain environments. However, annual rainfall totals alone may not adequately represent ecologically available water. Rainfall timing, event intensity, dry-spell duration, infiltration, and soil-water retention may be equally important for seed germination and plant establishment [6].

In Dhofar, the Khareef introduces an additional complication because vegetation receives moisture through fog interception and drizzle as well as rainfall. Hildebrandt and Eltahir (2006) demonstrated that cloud-water capture contributes to the maintenance of seasonal woodland ecosystems. Consequently, changes in cloud frequency, cloud-base elevation, fog duration, or atmospheric moisture transport could influence vegetation even without substantial changes in recorded rainfall. Nevertheless, the ecological importance of fog should not be confused with demonstrated evidence of a long-term decline in fog occurrence [6]. Establishing such a trend requires consistent multidecadal observations, suitable satellite products, and reliable methods for distinguishing cloud immersion from precipitation.

Spatial heterogeneity and climate attribution

Mountain environments exhibit considerable climatic variability over short distances. North-facing slopes, shaded valleys, exposed ridges, and sheltered depressions may experience different temperature and moisture conditions despite their geographical proximity. This spatial heterogeneity complicates the interpretation of regional climate trends. Meteorological observations from coastal stations or lowland settlements may not adequately characterize high-elevation microclimates. Similarly, coarse-resolution climate projections may fail to represent local orographic precipitation and fog processes. Therefore, a rigorous

assessment of climate change in Oman's mountains should combine station observations, elevation-aware climate datasets, local microclimate measurements, and carefully validated regional climate projections [10].

Impacts of Climate Change on Plant Biodiversity

Vegetation health and mortality

One of the clearest documented examples of ecological vulnerability in northern Oman concerns the decline of montane juniper populations. Earlier field surveys identified poor woodland condition and limited reproductive activity at relatively exposed, lower-elevation sites [4]. Later studies strengthened the evidence linking population condition to climatic stress.

MacLaren (2016) found that juniper health and regeneration were associated with cooler, wetter conditions [5], while Al Haddabi and Victor (2016) documented low regeneration in their surveyed woodland populations [9]. Together, these investigations indicate that the long-term persistence of juniper woodlands may be threatened by the combined effects of climatic stress and limited recruitment. However, mature-tree mortality and poor regeneration should be evaluated separately. Established trees may survive prolonged unfavourable conditions, whereas seedlings and saplings can be highly sensitive to short periods of drought and elevated temperature. Thus, apparently persistent woodlands may experience gradual demographic deterioration if new individuals fail to replace ageing trees.

Seedling establishment and regeneration

Successful regeneration is essential for the long-term resilience of mountain plant communities. Climate-related changes in soil moisture and temperature can affect germination, seedling survival, root development, and establishment. Experimental work by Al Farsi and colleagues investigated the responses of *Juniperus seravschanica* saplings to temperature and watering treatments [10,11]. Reduced irrigation significantly decreased sapling growth under otherwise favourable temperatures. Field transplantation also demonstrated differences in establishment success across elevations, with older saplings generally showing greater survival than younger individuals. These findings are particularly relevant to conservation because they suggest that assisted regeneration may be possible, but its effectiveness depends on planting material, site conditions, and sustained monitoring.

Altitudinal redistribution and habitat contraction

Climate warming may alter the elevational distribution of plant species by changing the location of suitable temperature and moisture conditions. In mountain systems, upward shifts can reduce the available habitat area for species restricted to high elevations. Evidence from Omani juniper studies is consistent with greater climatic stress at lower elevations and comparatively favourable conditions in cooler mountain habitats. Nevertheless, the interpretation of such patterns requires caution. An observed difference in tree condition across elevations does not, by itself, establish that a population has migrated upslope over time. Demonstrating an actual distributional shift requires repeated spatial surveys, historical occurrence records, or other comparable observations capable of distinguishing changes in occupancy from differences in survival and recruitment [10].

Fog-dependent ecosystems and ecological feedbacks

The cloud-influenced woodlands of Dhofar may be particularly sensitive to changes in atmospheric moisture and vegetation structure. Their vulnerability arises not only from potential changes in climate but also from the dependence of local moisture availability on existing vegetation. Hildebrandt and Eltahir (2006) demonstrated that tree canopies enhance cloud-water capture and that degraded vegetation may lose this additional moisture source [6]. The resulting reduction in water availability can inhibit woodland regeneration, potentially reinforcing degradation. This mechanism illustrates why the ecological consequences of woodland loss may extend beyond the immediate removal of trees. Degradation can alter local hydrological conditions, making restoration more difficult even if the original climatic conditions remain broadly unchanged.

Biodiversity composition and ecological interactions

Climate-related changes in dominant vegetation may also affect associated plant communities. Alterations in canopy cover can influence shade, soil temperature, litter accumulation, soil moisture, and the availability of protected microsites. In juniper woodlands, changes in tree density could affect the establishment of understory species and the spatial distribution of suitable habitats. Similarly, degradation of Dhofar's seasonal woodlands may alter the balance between woody vegetation, grasses, and shrubs. Such responses are ecologically plausible, but comprehensive evidence for climate-driven changes in whole-community composition remains limited for Oman's mountains. This distinction is important: species-level studies establish vulnerability, whereas broader claims about biodiversity loss require repeated floristic surveys and quantitative community data [11].

Ecological Vulnerability and Conservation Challenges

Climate change is not the only threat to Oman's mountain biodiversity. Grazing, habitat degradation, infrastructure development, and land-use change may act independently or interact with climatic stress. Their combined effects can reduce vegetation resilience and complicate the identification of underlying drivers. In northern Oman, browsing pressure and disturbance can reduce the establishment of young trees, while drought and heat stress may further constrain regeneration. In Dhofar, grazing-induced canopy degradation is especially significant because woodland loss can reduce fog-water interception. The hydrological consequences of canopy degradation may therefore persist beyond the initial disturbance [6].

The principal conservation challenge is to avoid treating all vegetation deterioration as a direct consequence of climate change. For example, reduced seedling recruitment may result from moisture limitation, browsing, poor seed viability, or combinations of these factors. Effective conservation requires evidence capable of distinguishing these mechanisms [8].

Adaptation and Conservation Strategies

Climate-informed conservation in Oman's mountain ecosystems should prioritize the protection of existing vegetation, restoration

of degraded habitats, and maintenance of suitable microclimatic refugia.

In the Al Hajar Mountains, conservation efforts should focus on protecting surviving juniper populations, reducing disturbance in regeneration areas, and identifying locations with favourable moisture and temperature conditions. Al Farsi et al. (2017) demonstrated that transplantation of nursery-grown juniper saplings can improve establishment compared with direct seed sowing. Their results also indicate that plant age and planting-site conditions substantially influence restoration success [10].

In Dhofar, maintaining woodland canopy structure should be a major conservation priority because vegetation contributes directly to local moisture capture. Grazing management, protection of woodland regeneration areas, and restoration of degraded cloud-influenced habitats may help preserve this ecological function. Conservation planning should also account for endemic and geographically restricted species, particularly where suitable habitats occupy small or fragmented areas. Restoration should use locally appropriate plant material and avoid introducing species or genotypes without evaluating ecological compatibility [9].

Research Gaps and Future Perspectives

The available literature provides important evidence of ecological vulnerability but reveals several limitations that should guide

future research. They are: (i) Long-term ecological monitoring remain essential. Repeated vegetation surveys along fixed elevational transects could establish whether plant communities are experiencing changes in species richness, composition, recruitment, or mortality. (ii) Improved mountain climate observations are required. Monitoring networks should include temperature, relative humidity, rainfall, soil moisture, and, where relevant, fog duration and cloud-water interception. (iii) Climate projections should be linked to species-level ecological information. Species distribution modelling could identify potential changes in habitat suitability under alternative climate scenarios. However, predictions must account for the uncertainty associated with climate models, species occurrence records, and assumptions about dispersal. (iv) Studies should explicitly investigate interactions between climate and land use. Paired grazing-exclusion and control plots, combined with environmental monitoring, could help distinguish the effects of herbivory from those of climatic stress. (v) Integrating satellite observations with field measurements would improve assessments of vegetation change across inaccessible mountain habitats. Remote sensing could be used to examine seasonal vegetation dynamics, canopy cover, and long-term landscape changes, provided that satellite indicators are validated against ground observations (Table 2).

Table 2. Summary of evidence and research priorities

Ecological issue	Current evidence	Evidence limitation	Research priority
Juniper decline	Field studies link condition to temperature and moisture	Limited species coverage	Long-term population monitoring
Juniper regeneration	Experimental evidence of drought and heat sensitivity	Limited long-term establishment records	Restoration trials
Dhofar cloud woodland	Strong evidence for fog-water interception	Limited long-term fog trends	Fog and canopy monitoring
Altitudinal distribution	Elevation-related differences in vegetation condition	Incomplete repeated distribution surveys	Permanent elevational transects
Endemic plant vulnerability	Historical conservation assessments	Updated assessments needed	Species-level inventories
Climate-grazing interactions	Evidence of interacting pressures	Attribution remains difficult	Controlled ecological studies

Conclusion

The mountain ecosystems of Oman support distinctive plant biodiversity maintained by contrasting climatic and hydrological conditions. The Al Hajar Mountains contain climate-sensitive juniper woodlands, whereas the Dhofar Mountains support seasonally cloud-influenced vegetation dependent on atmospheric moisture and canopy-mediated water capture. Published research provides evidence of climatic vulnerability in northern juniper populations and demonstrates the importance of vegetation–moisture feedbacks in southern woodland ecosystems. However, evidence of widespread climate-driven biodiversity loss remains insufficient, particularly at the plant-community level. Climate change also interacts with grazing, habitat degradation, and land-use pressures, requiring integrated ecological assessments rather

than single-factor explanations. Future conservation should prioritize long-term monitoring, protection of climatic refugia, restoration of degraded habitats, and improved integration of climate observations with biodiversity data. These measures are essential for maintaining the ecological resilience of Oman's mountain ecosystems under changing environmental conditions.

References

1. Körner, C. (2004). Mountain biodiversity, its causes and function. *AMBIO: A Journal of the Human Environment*, 33(sp13), 11-17.

2. Rahbek, C., Borregaard, M. K., Colwell, R. K., Dalsgaard, B. O., Holt, B. G., Morueta-Holme, N., ... & Fjeldså, J. (2019). Humboldt's enigma: What causes global patterns of mountain biodiversity? *Science*, 365(6458), 1108-1113.

3. Pauli, H., Gottfried, M., Dullinger, S., Abdaladze, O., Akhalkatsi, M., Alonso, J. L. B., ... & Grabherr, G. (2012). Recent plant diversity changes on Europe's mountain summits. *Science*, 336(6079), 353-355.
4. Gardner, A. S., & Fisher, M. (1996). The distribution and status of the montane juniper woodlands of Oman. *Journal of biogeography*, 23(6), 791-803.
5. MacLaren, C. A. (2016). Climate change drives decline of *Juniperus seravschanica* in Oman. *Journal of Arid Environments*, 128, 91-100.
6. Hildebrandt, A., & Eltahir, E. A. (2006). Forest on the edge: Seasonal cloud forest in Oman creates its own ecological niche. *Geophysical Research Letters*, 33(11).
7. Vadivel, G., & Sivamani, S. (2024). Impact of tropical cyclones in Oman: a concise overview. *ISAR J. Sci. Technol*, 2(7).
8. Mohan, U., Selvaraju, S., Narayanagounder, S., Eswaravelu, D., & Govindasamy, V. (2024, March). Artificial neural network modelling for prediction of meteorological parameters in Dhofar Governorate of Sultanate of Oman. In *AIP Conference Proceedings* (Vol. 3042, No. 1, p. 020033). AIP Publishing LLC.
9. Al Haddabi, L., & Victor, R. (2016). The ecological status of juniper woodlands in Al Jabal Al Akhdar, northern mountains of Oman. *International Journal of Environmental Studies*, 73(5), 746-759.
10. Al Farsi, K. A., Lupton, D., Hitchmough, J. D., & Cameron, R. W. (2017). How fast can conifers climb mountains? Investigating the effects of a changing climate on the viability of *Juniperus seravschanica* within the mountains of Oman, and developing a conservation strategy for this tree species. *Journal of Arid Environments*, 147, 40-53.
11. Al Farsi, K., Cameron, R., Hitchmough, J., & Lupton, D. (2016). Assessing the effects of drought and temperature on the establishment of *Juniperus seravschanica* saplings in Northern Oman. *Sibbaldia: The International Journal of Botanic Garden Horticulture*, (14), 37-53