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Impact of Climate Change on Biodiversity in High-Altitude Regions of Developing Countries

Mohammad Yosuf Sadat*[1], Ayaz Khan Naseri[2]
[*1]Department of Forestry and Natural Resources, Agriculture Faculty, Kabul University, Kabul Afghanistan
[2]Department of Agricultural Economics & Extension, Agriculture Faculty, Kabul University, Kabul Afghanistan
*Corresponding author email: Mohammadyousafsadat@gmail.com

Abstract

Climate change is progressively influencing biodiversity in high-altitude environments, especially in developing nations where resources for adaptation are scarce. These places, home to a broad diversity of unique species, serve a significant role in supporting local communities by providing vital ecosystem services, such as water control and agricultural assistance. This study explores the ways in which climate change affects biodiversity in high-altitude environments, focusing on changes in species distribution, ecological disturbances, vulnerability of native species, and broader impacts on local communities. To achieve these objectives, a narrative review method was employed, which provides a comprehensive understanding of the topic by collecting, analyzing, and synthesizing findings from previous research. The current study demonstrates many species are moving to higher altitudes in pursuit of adequate habitats as global temperatures rise, but endemic species are more vulnerable to extinction due to habitat fragmentation and limited adaptability. Furthermore, the deterioration of ecosystem services worsens problems like food insecurity, poverty, drought and water scarcity in vulnerable populations. As well, the research highlights the need for long-term research, better models of species migration, and more focus on the socioeconomic effects of biodiversity loss in developing countries. The evaluation urges climate-resilient legislation, sustainable land-use practices, natural resources management and immediate conservation action to lessen the adverse effects of climate change. Urgent conservation and climate-adaptive policies are needed to protect high-altitude biodiversity and support local communities.

Key words: Biodiversity, Climate change, Ecosystems, Resilience, Species

تأثیر تغییرات اقلیمی بر تنوع حیات در مناطق ارتفاعات بلند کشورهای در حال توسعه

محمد یوسف سعادت[1]، ایازخان ناصری[2]
[1]د څنګلپوهنې او طبیعي سرچینو څانګه، کرنې پوهنځی، کابل پوهنتون
[2]د کرنیز اقتصاد او توسعې څانګه، کرنې پوهنځی، کابل پوهنتون

خلاصه

تغییرات اقلیمی به طور روز افزون بر تنوع حیات در محیط‌های با ارتفاعات بلند تاثیر می‌گذارد، به خصوص در کشورهای در حال توسعه که منابع برای توافق با این تغییرات محدود می باشد. این مناطق، که خانه‌ای برای انواع متنوع و منحصر-به فرد هستند، نقش مهمی در حمایت از جوامع محلی، از جمله فراهم نمودن خدمات حیاتی ایکوسیستم مانند کنترول آب و کمک به زراعت، ایفا می‌کنند. این مطالعه به بررسی تأثیرات تغییرات اقلیمی بر تنوع حیات در محیط‌های مرتفع می‌پردازد و تغییرات در انتشار انواع، حوادث ایکولوژیکی، آسیب‌پذیری انواع بومی و تأثیرات وسیعي بر جوامع محلی را مورد توجه قرار می‌دهد. برای رسیدن به این اهداف، از روش مرور روایتی استفاده شده که به فهم جامع‌تری موضوع از طریق جمع‌آوری، تجزیه و تحلیل و تلفیق یافته‌های تحقیقات پیشین می‌پردازد. این مطالعه نشان می‌دهد که بسیاری از انواع به دنبال زیستگاه‌های مناسب به ارتفاعات بلندتر مهاجرت می‌کنند درحالیکه انواع بومی به دلیل تخریب و تکه شدن زیستگاه‌ها و تطابق محدودشان در معرض انقراض بیشتر قرار دارند. علاوه بر این، تخریب خدمات ایکوسیستم مشکلاتی مانند ناامنی غذایی، فقر، خشکسالی و کمبود آب را در جمعیت‌های آسیب‌پذیر تشدید می‌کند. همچنین، ضرورت به انجام تحقیقات درازمدت، مدل‌های بهتر مهاجرت انواع و تمرکز بیشتر بر اثرات اجتماعی-اقتصادی از دست رفتن تنوع حیات در کشورهای در حال توسعه تأکید دارد. این ارزیابی خواستار تصویب قوانین مبارزه در برابر تغییرات اقلیمی، شیوه‌های پایدار استفاده از اراضی، مدیریت منابع طبیعی و اقدامات فوری حفاظتی برای کاهش اثرات منفی تغییرات اقلیمی است. پالیسی های حفاظتی و انطباقی با تغییرات اقلیمی فوری برای حفاظت از تنوع حیات در ارتفاعات بلند و حمایت از جوامع محلی ضروری پنداشته می شود.

کلیمات کلیدی: تنوع حیات، تغییرات اقلیمی، ، ایکوسیستم، مقاومت، انواع

Introduction

One of the biggest worldwide issues of the twenty-first century is climate change, which has serious ramifications for ecosystem stability and biodiversity. Extreme weather events have become more frequent and severe as a result of the rise in global temperatures, which is mostly attributable to human activity like the burning of fossil fuels and deforestation (IPCC, 2021). Even though climate change affects the entire world, it particularly threatens high-altitude ecosystems in developing nations.

In addition to being vital for preserving biodiversity worldwide, these areas give local inhabitants access to pivotal resources, including food, water, and a means of subsistence. High-altitude locations host a wide variety of organisms that have adapted to thrive in specific climatic conditions. Nevertheless, these ecosystems are extremely vulnerable to variations in precipitation and tempera-ture (Pauli et al., 2012). As global temperatures rise, species in these regions frequently relocate to higher elevations or latitudes in response to shifting climates (Guisan & Zimmermann, 2000). For instance, research indicates that species in the Alps have risen by an average of 29 meters per ten years (Rumpf et al., 2018). The physiological and ecological functions of plants and animals in high-altitude areas are strongly linked to stable environmental conditions, which makes them especially susceptible to disruption from climate change (Körner, 2007).

In underdeveloped nations, where resources for adaptation measures are frequently scarce, the effects of climate change are especially acute. Food insecurity, poverty, drought and lack of access to clean water are just a few of the socioeconomic issues that can be made worse in these areas by the loss of biodiversity brought on by climate change (Bellard et al., 2012). Known as the “water towers” of the

earth, mountains are essential for maintaining agriculture in neighboring lowland regions and controlling water cycles (Viviroli et al., 2007). The consequences for human populations in these regions might be severe, endangering both livelihoods and regional development as these ecosystems change as a result of shifting climatic circumstances.

Furthermore, indigenous species that might not be able to move or adapt to 70ediment-ingly hostile settings may go extinct as a result of biodiversity loss in high-altitude areas of emerging nations. The capacity to migrate to new, more suitable habitats becomes more important as species deal with habitat loss and fragmentation, yet chances for high-altitude species may be limited (Pauli et al., 2012). The continuous deterioration of these habitats emphasizes how crucial it is to comprehend the exact processes by which species distribution, ex-tinction rates, and ecosystem functions are being impacted by climate change.

With an emphasis on the fragility of endemic species, changes in ecological processes, and the wider so-cioeconomic ramifications of these changes, this review aims to investigate the complex effects of climate change on biodiversity in high-altitude areas of developing nations. This re-search seeks to create a better understanding of how climate change is altering ecosystems and provides insights into practical conservation tactics that can lessen the effects of climate change on biodiversity in these vulnerable areas by combining recent studies.

Methodology

This study conducted an extensive literature search using databases such as Google Scholar, Web of Science, Scopus, and JSTOR. The search criteria included topics such as climate change, biodiversity, high-altitude ecosystems, developing countries, mountain ecosystems, species distribution, endemic species, ecosystem functioning and adaptation. These parameters ensured that the current research captured relevant studies focused on the impacts of climate change on biodiversity in high-altitude regions, particularly in the context of developing nations. Study types include government and non-governmental organization reports, peer reviewed as well as journal papers.

Results

This review categorizes existing studies into key thematic areas, including species distribution shifts, ecosystem service disruptions, the vulnerability of endemic species, adaptive strat-egies, and socioeconomic effects. High-altitude ecosystems harbor a significant proportion of endemic species that exhibit heightened sensitivity to climate fluctuations. Due to their lim-ited adaptability and restricted migration opportunities, these species face an elevated risk of extinction (Körner, 2007).

The resulting loss of biodiversity in these regions has profound im-plications for local communities. As critical ecosystem services such as water provision and agricultural support are increasingly disrupted, challenges such as food insecurity, poverty, drought and restricted access to clean water become more pronounced (Bellard et al., 2012).

A key finding of this review is the insufficient availability of long-term studies, the need for comprehensive modeling of species migration, and the inadequate consideration of socioeco-nomic dimensions related to biodiversity loss in developing nations. Addressing these re-search gaps is imperative for advancing our understanding of climate change's impact on high-altitude ecosystems.

A synthesis of the literature indicates notable changes in species distribution, ecosystem functionality, and socioeconomic conditions across high-altitude re-gions in developing countries.

Species Distribution Shifts

Species inhabiting high-altitude ecosystems are increasingly migrating to higher elevations in response to rising temperatures, with recorded shifts averaging 29 meters per decade (Rumpf et al., 2018).

However, many endemic species are unable to migrate due to ecological constraints, leading to heightened extinction risks (Pauli et al., 2012).

Climate change is driving significant shifts in species distributions across various ecosystems. In East African mountains, agroforestry trees like Mangifera indica and Persea americana are shifting altitudinally, altering carbon storage and affecting livelihoods (Odeny et al., 2019). Europe faces the northward expansion of Ambrosia artemisiifolia, increasing allergenic pollen exposure due to climate-driven changes (Storkey et al., 2014). In developing countries, climate variability disrupts livestock zones, forcing shifts in ق grazing and production systems (Musemwa et al., 2012). Meanwhile, marine species in the North Atlantic experience range shifts that may reduce genetic diversity, especially in southern populations (Provan, 2013). These distributional changes challenge traditional conservation models and require adaptive policy responses.

Ecosystem Disruptions

Alterations in precipitation patterns and rising temperatures have significantly impacted nutrient cycling, species composition, and overall biodiversity. In certain regions, these environmental shifts have contributed to the degradation of essential ecosystem services, including water regulation and soil fertility (Viviroli et al., 2007).

Climate change significantly alters ecosystem distributions by driving species to shift their ranges due to changes in temperature and precipitation, leading to habitat fragmentation and biodiversity loss (Kumar et al., 2012). Increased frequency of extreme weather events, such as droughts and floods, disrupts species composition and accelerates ecosystem degradation (Chen et al., 2020; Paudel, 2010). These changes impair vital ecosystem services like pollination and disease regulation, thereby threatening food security and livelihoods (Paudel, 2010). Additionally, the decline in biodiversity undermines traditional knowledge systems, such as the Ayurvedic medicinal practice in the Himalayas, highlighting the intricate link between cultural heritage and ecological health (Kumar et al., 2012).

Vulnerability of Endemic Species

Endemic species in high-altitude ecosystems are particularly susceptible to climate variability. Limited adaptability and migration opportunities render these species highly vulnerable to extinction (Körner, 2007). Additionally, habitat fragmentation further exacerbates this issue, reducing the availability of suitable habitats necessary for their survival.

Endemic species—organisms restricted to specific geographic locations—are highly vulnerable to climate change due to their specialized habitat requirements, limited dispersal capacity, and narrow ecological niches. As climate change alters temperature, precipitation, and sea levels, these species often cannot adapt or relocate quickly enough (Schut et al., 2017).

Socioeconomic Impacts

Biodiversity loss in high-altitude regions carries profound socioeconomic implications, particularly for communities that rely directly on fragile mountain ecosystems. The degradation of essential ecosystem services such as freshwater provision, soil fertility, pollination, and agricultural productivity exacerbates existing vulnerabilities, intensifying food insecurity, poverty, drought, and inadequate access to clean water (Bellard et al., 2012). Mountainous regions are often described as the “water towers of the world,” supplying freshwater to millions of people in downstream lowland areas. Any disruption to these ecosystems therefore undermines not only local livelihoods but also national and regional water security.

Moreover, reduced biodiversity diminishes the resilience of agro-ecosystems, making farming systems more susceptible to pests, diseases, and climate variability. This decline threatens subsistence agriculture, which remains the primary source of income and food for many rural households in developing countries. The socio-economic consequences extend further, affecting cultural practices, traditional medicine, and ecotourism opportunities that depend on intact biodiversity. In the long term, the erosion of biodiversity undermines sustainable development by increasing social instability, deepening poverty cycles, and constraining adaptation options in the face of climate change.

Discussion

The findings of this review highlight the profound impacts of climate change on biodiversity in high-altitude regions of developing countries. The heightened vulnerability of endemic species, coupled with anticipated shifts in species distribution, poses a substantial risk of long-term ecological imbalance. These ecosystems are already subject to considerable anthropogenic pressures, including deforestation, land-use change, and resource extraction. Climate change compounds these stressors, generating feedback loops that accelerate habitat degradation and species loss.

The socioeconomic repercussions of these ecological changes are equally severe. Mountain ecosystems in many developing countries play a pivotal role in sustaining local livelihoods through agriculture, water provision, and cultural practices. The disruption of these critical ecosystem services not only undermines daily subsistence for local communities but also threatens broader regional development goals. Declining biodiversity is likely to exacerbate poverty and food insecurity, thereby intensifying social instability and vulnerability.

Furthermore, the upward migration of species in response to increasing temperatures presents significant challenges for conservation efforts. Habitat loss, in conjunction with the limited adaptive capacity of many species, underscores the urgent need for comprehensive and targeted conservation strategies. Proactive and science-based measures are essential to safeguard these fragile ecosystems and to mitigate the cascading ecological and socioeconomic consequences of climate change.

Conclusion

Climate change is already having a profound impact on biodiversity in high-altitude ecosystems, particularly in developing countries. The vulnerability of endemic species, combined with the shifting ecological dynamics, presents significant challenges for both conservation and human development. These regions, which are essential for water regulation, agriculture, and local livelihoods, are facing severe disruptions as a result of temperature increases, altered precipitation patterns, and habitat fragmentation. Immediate action is required to understand and mitigate these impacts through both scientific research and on-the-ground conservation initiatives. Efforts to preserve high-altitude biodiversity must prioritize the protection of endemic species, the restoration of ecosystem services, and the improvement of adaptation strategies. To address these challenges, governments should implement climate-resilient policies, strengthen conservation efforts, and support sustainable land-use practices. Stakeholders, including conservation organizations and local communities, must collaborate to protect biodiversity and enhance ecosystem resilience. Future research should focus on long-term species monitoring, improved climate adaptation models, climate Smart Agriculture and the socioeconomic dimensions of biodiversity loss. Immediate action is necessary to mitigate these impacts and ensure sustainable development in high-altitude regions.

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