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OPINION PAPER

Ecosystem Health and Risk Assessments for High Conservation Value Mountain Ecosystems of South Asia: A Necessity to Guide Conservation Policies

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Abstract
Mountain ecosystems across South Asia are facing huge pressure and are threatened by different drivers of loss. Red List of Ecosystems, to assess risks and ecosystem health, offers an exciting prospect to address complex challenges faced by ecosystems. This opinion is an outcome of the brainstorming organized to mark the International Mountain Day in December 2020, followed by further discussions among key stakeholders for initiating the Red List of Ecosystem (RLE) assessment in the region. As an initial endeavor, we have explored the evidence available to be integrated with the basic RLE requirements to undertake the ecosystem health assessment for mountain ecosystems in South Asia. We argue that the existing data gaps and insufficient understanding of the RLE process are a key-barriers to initiating ecosystem health assessment for supporting and contributing to knowledge-based conservation, governance, livelihood, land use, and macroeconomic planning. The RLE-based planning should be expanded and implemented for diverse ecosystems by enhancing transboundary cooperation, research collaboration, co-production of knowledge, and involving local communities. This opinion paper is an effort to facilitate, encourage and enhance discussions among wider stakeholders for developing a multidisciplinary and transdisciplinary network of experts in the region for undertaking large scale RLE assessment for different mountain ecosystems that are threatened by an array of drivers of biodiversity and ecosystem services loss. This can guide strategic conservation efforts to halt and reverse the losses by community supported landscape restoration programmes.

Keywords South Asia · Mountains · Himalayas · Ecosystem Health Assessment · Red List of Ecosystems · Restoration

1 Introduction

Mountain regions across the world having complex human–environment systems show a discrete susceptibility to the existing vital alteration in the Earth System that is determined by anthropogenic interventions and is experiencing a hasty change in Anthropocene (Schickhoff et al. 2022). Mountains are home to 20% of the world's population and makeup 24% of the global land area, providing 60–80% of the world's freshwater supply and other relevant nature's contributions to human well-being. Mountains are also home to 50% of the world's biodiversity hotspots (Xu et al. 2019). Mountain communities are globally one of the most marginalized groups, who are likely to face even greater adversities in surviving future challenges, such as climate change and disaster risks (Dhyani and Dhyani 2016a; Cusick 2018; Sharma 2018). For years mountain communities have faced poor and unreliable access to infrastructure, essential services, and financial support and are often marginalized

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from large political processes because of their remoteness, inaccessibility, and hostile terrains (Gioli et al. 2019). A recent study by FAO-Mountain Partnerships, released on International Mountain Day, 2020, estimates that one in two rural mountain people in developing countries are facing vulnerability to food insecurity (Romeo et al. 2020). There is a general lack of pro-mountain policies and an urgent need to tackle hunger and malnutrition in the mountains and radically transform mountain food systems that can ensure food security, sustainability, and conservation of agro-biodiversity. Conservation of these unique and fragile ecosystems is key to achieving long-term regional conservation benefits and a sustainable future for more than 1.5 billion upstream and downstream communities. Unfortunately, high conservation value mountain ecosystems in South Asia face tremendous threats from ongoing climate change, land degradation, deforestation, developmental projects and unsustainable use, coupled with over-exploitation of wild resources. As the global climate continues to warm, higher mountain areas in South Asia are expected to experience at least three times higher warming (IPCC 2018). The South Asian region is one of the highly biodiverse regions, having unique biogeographic diversity within and across different countries, having four global biodiversity hotspots (Himalayas, Western Ghats and Sri Lanka, Indo-Burma and Sundaland that constitutes of Nicobar Islands). Characters of mountain ecosystems are equally diverse across the South Asia region. The snowclad high-altitude Himalayas, home to the world's highest peak the Everest, the Hindu Kush, the Karakoram, the desert mountains of the Aravalli, the peninsular Eastern and Western Ghats, the Maragala Mountain Range, Vidhyan hills, Salt range, Spin Ghar, Alagalla Mountain Range, Knuckles Mountain Range and many other important mountain chains of the region are vital support to the life and livelihood of people living in different countries and transboundary areas of the region. The Hindu Kush Himalayas (HKH) are recognized globally for their supply of numerous ecosystem services that help more than 1.5 billion people directly in maintaining their life support system in South Asia and the larger global community indirectly (Baral et al. 2017; Sharma et al. 2019) (Fig. 1). The unique buffering capacity of the forest and rangeland ecosystems across the Himalayas and other mountain chains of this region help in slope stability, regulating hydrological flow and enhancing ecological integrity. The HKH mountain ecosystems sustain high levels of biodiversity and ecosystem

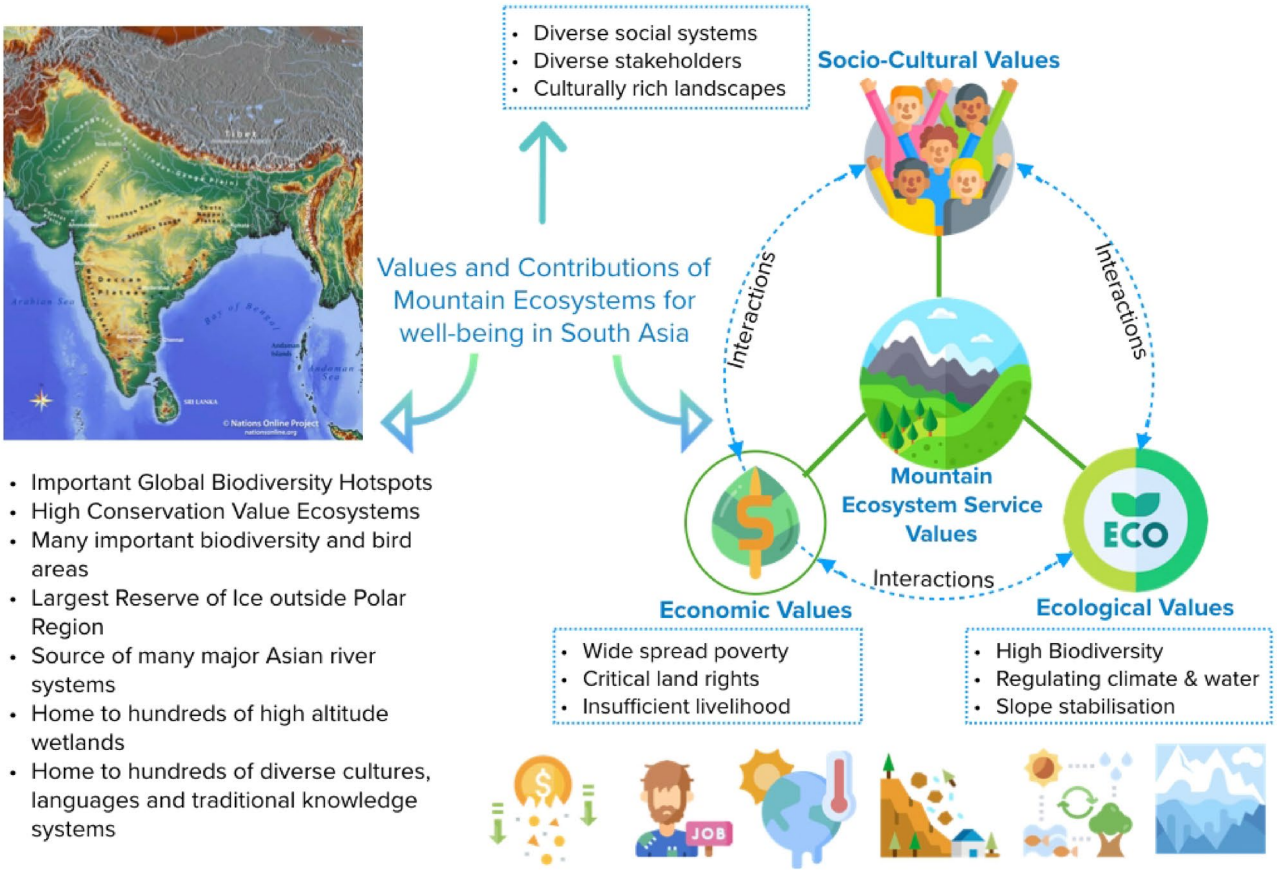

Fig. 1 Values and contributions of high conservation value mountain ecosystems in South Asia (Adapted from Baral et al. 2017)

services for ensuring human well-being (Pandit 2013; Madhav et al. 2017; Sharma et al. 2019; Xu et al. 2019). Western Ghats is a similar ecosystem, a veritable treasure house of biodiversity, harbouring more than 30% of all plant, fish, herpeto-fauna, bird, and mammal species found in India and supporting the life and livelihood of about 245 million people (Daniel et al. 2011; WWF). While biodiversity and ecosystem services have driven the rapid economic growth and prosperity in the region, it has come at the expense of high environmental degradation and biodiversity loss. Both climate and non-climate stressors are projected to directly affect these mountain ecosystems, resulting in biodiversity loss and reduced ecosystem services (Dhyani et al. 2013a, 2019; Dhyani and Dhyani 2020).

The IPBES Asia Pacific Regional Assessment Report (2018) documents that South Asia's biodiversity loss is second only to South East Asia, is at a critical stage. The Global Biodiversity Outlook 5 (GBO) by Convention on Biodiversity (CBD) indicates the HKH mountain biodiversity is facing unprecedented threats from extreme weather events, invasive alien species, agricultural intensification, past urbanization, glacier melting, and increasing waste and pollution. The IPBES Asia Pacific Regional Assessment Report, 2018, Global Assessment Report, 2019, followed by a comprehensive assessment of the HKH region through the Hindu Kush Himalayan Monitoring and Assessment Programme (HIMAP) report generated important scientific research-based knowledge and evidence on strengthening the social, economic and environmental pillars of sustainable mountain development in the region that can be used for evidence-based decision-making to safeguard the environment and advance people's well-being (IPBES 2018; Bongaarts 2019; Sharma et al. 2019). However, similar comprehensive assessments are lacking for other mountain systems in South Asia. The International Union for Conservation of Nature (IUCN) Red List of Ecosystems (RLE) Categories and Criteria developed by the IUCN Commission on Ecosystems Management (CEM) RLE Specialists group are global standards to assess the status of ecosystems (Keith et al. 2009; Sato and Lindenmayer 2018). It is anticipated that the application of RLE will be of great value to the different strategic groups of stakeholders engaged in the protection and management of mountain ecosystems in South Asia to prioritize conservation action (Fig. 2). While it was expected the RLE would be used to assess the ecosystem health for all the existing ecosystems across the world by 2022 due to COVID-19, the process got delayed but still except Myanmar and briefly one assessment at Sunderbans, no assessment has been undertaken so far for South Asia that was considered one of the high conservation priority areas among IUCN's eight statutory regions under IUCN's 2016–2020 intersessional programme (Sievers et al. 2020; Murray et al. 2020). The RLE assessment needs to be undertaken for some of the high conservation value mountain ecosystems in South Asia that include especially the Hindukush Himalayan range in Nepal, India, Pakistan, China, and Bhutan. This is of specific priority to help halt and reverse the loss of fragile and sensitive mountain ecosystems for the well-being of hundreds of native and indigenous mountain communities, supporting them with sustainable livelihoods using various Nature-based Solutions to control migration (Cohen-Shacham et al. 2016, 2019; Dhyani et al. 2020a, b).

Fig. 2 Word art entrenched on red list of ecosystem showing some of the major aspects of the importance of ecosystem health assessment using the IUCN approach (suggestive, not comprehensive) (http://www.wordart.com)

The findings discussed in this opinion paper are based on the outcome of the brainstorming event organized by the authors and attended by ecosystem experts and members of the South Asia Regional network of the IUCN Commission on Ecosystem Management (CEM) (https://www.iucn.org/commissions/commission-ecosystem-management/regions/south-asia) in association with FAO-Mountain Partnerships, Rome (http://www.fao.org/mountain-partnership/en/). This event was planned as a strategically important webinar (on 14 December 2020) to commemorate International Mountain Day 2020 (IMD 2020 on 11 December 2020) under the theme, 'Mountain Biodiversity'. The brainstorming event facilitated an active exchange of key ideas and opinions that was further followed up through multi-stakeholder discussions that helped in deepening knowledge on the importance of multi-dimensional threats posed by climatic and socio-economic changes and challenges on diverse mountain ecosystems in the region. The discussion participants were of the unanimous opinion that mountains across the region that provide fresh water, fertile soil, and regulate regional climate are facing significant stress and vulnerability due to diverse direct and indirect drivers. There are chances that many parts of the region, especially Hindukush Himalayas and the Western Ghats, might be already facing hidden collapse, an important category under RLE that indicates severe stress that may lead to damage of ecosystems and ecosystem services beyond repair. Ecosystem health assessment using emerging tools and methods, such as the RLE assessment developed by the IUCN CEM for Hindukush Himalayan, Western Ghats, Hindukush Himalayan ecosystems, could be better protected for the future to ensure unrestricted flow of services and benefits for the upstream and larger downstream communities. The event saw expert presentations by speakers followed by an interactive panel discussion and brainstorming with specialists and practitioners to ensure maximum audience interactions.

2 RLE Assessment for Mountain Ecosystems in South Asia

South Asian mountains are unique with their rich biodiversity, high endemism, and is home to two important global biodiversity hotspots (Chitale et al. 2014). Nature also has a significant influence on the rich cultural and linguistic diversity of these ecosystems. These mountain ecosystems play an immense role in creating a unique natural–cultural biodiversity hotspot (Urban 2020), home to over 35,000 species of plants (Barman 2019). Mountain agriculture and agro-biodiversity are also unique and key to sustainable food systems that have the potential to contribute to global food security and can be considered the cradle for future food crops that can survive climatic stress and warrants protection too (Misra et al. 2008a, b). Many economically and socially important indigenous mountain crops, such as millets, pseudo millets, proso millets, legumes, and many traditional livestock varieties of yak, sheep, goats, etc., diversify these biodiversity-rich landscapes (Dhyani et al. 2011; Dhyani 2018). Of the seven major mountain ranges of the region, so far, the HKH region, Western Ghats, have received the most recognition and has been well-acknowledged as the water tower for the larger part of Asia and the third pole. In general, the region provides a huge support system for millions of people living across India, Nepal, Bhutan, Bangladesh, parts of Pakistan, and Myanmar living in the mountains.

While there is still shortage of information on many the status of threatened species of plants and animals databases developed by ICIMOD (https://www.icimod.org/ecosystem-services/hkh-bif/), Eastern Himalayas office of Ashoka Trust for Research in Ecology and Environment (ATREE), Zoological Survey of India, Botanical Survey of India, Wildlife Institute of India, GB Pant National Institute on Himalayan Environment, India, Royal Society for Protection of Nature, Bhutan, many NGOs, and academic organizations have given their untiring efforts in exploration, identification and threat assessments for many floral and faunal species in the region and can be used as a rich data base. The Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) Regional Assessment reported that 22% of all species and 25% of endemic species in the region fall under various threatened categories of the IUCN red list (www.iucnredlist.org) (Sultan-Ud-Din et al. 2016; IPBES 2018; Gowthami et al. 2021). They are either extinct, extinct in the wild, or are critically endangered or vulnerable. Overexploitation of bio-resources has driven many high-value trees as well as medicinal species, such as *Ilex khasiana* Purkay, *Nepenthes khasiana* Hook.f., *Cordyceps sinensis* (Berk.) Sacc., *Trillium govanianum* Wall. ex D.Don, *Taxus baccata* L., in Hindukush Himalayas, *Pterocarpus santalinus* L., *Syzygium travancoricum* Gamble, *Dipterocarpus bourdillonii* Brandis in the Western Ghats and hundreds of other threatened species to the brink of extinction (Barik et al. 2018; Dhyani and Dhyani 2020). Similarly, there are hundreds of threatened animal species viz. *Panthera uncia* Schreber (Snow Leopard), *Neofelis nebulosa* Griffith (Clouded Leopard), *Ailurus fulgens* Cuvier (Red Panda), *Macaca silenus* L., *Macaca radiata* Geoffroy, *Macaca munzala* Madhusudan & Mishra, *Macaca assamensis* McClelland, *Macaca sinica* L., *Macaca arctoides* Geoffroy, *Macaca mulatta* Zimmermann, *Macaca leonina* Blyth, *Rhinoceros unicornis* L., *Hemitragus jemlahicus* Smith, *Nilgiritragus hylocrius* Ogil by, etc. that are threatened due to diverse direct and indirect drivers of loss. Roughly one in three freshwater fish species is threatened by overexploitation, invasive alien species, disease and pollution. Sixty percent of the grasslands are degraded due to unsustainable grazing,

encroachment by invasive alien species, or land conversion for expanding agricultural activities (IPBES 2018; Xu et al. 2019). 19% of all species and 45% of endemics of South Asia are at risk, the largest number specieswise (Clark et al. 2013). The rest of the lesser discussed but equally important mountain chains in the region, namely, the Karakoram in the North, the Aravalli, the Vindhyas and Satpuras in Central India, the Eastern Ghats, Salt range, Spin Ghar, Alagalla Mountain Range, and others, also require substantial funding and efforts to enhance exploration, identification and threat assessment for diverse species. One of the major reasons that other small mountain ranges other than the Hindukush Himalayas and the Western Ghats have not received due consideration is because of their presence limited to one country and not in transboundary areas and limited information on the biodiversity. However, there is a need that after we initiate and complete ecosystem health assessment for high conservation value ecosystems in Hindukush Himalayas followed by the Western Ghats, we also support efforts for ecosystem health assessment for these mountain chains as many of them, such as Aravali and Shivalik, are already disappearing on a rapid rate and facing huge deforestation because of ongoing development and urban expansion.

Most of the conservation efforts and government policies have so far focused on enhancing development, increasing plantations, and protected area coverage insensitive and fragile mountain terrains to ensure protection and socio-economic development, though, many times, it comes at the cost of alienating local and indigenous communities from the landscapes, where they were living for generations. However, comprehensive management planning and socio-ecologically sound policies based on scientific evidence are crucial. The development of a conceptual model from available data and understanding larger impacts of invasive species, drivers of land, and ecosystem degradation, followed by changes particular to the various local ecosystems, is important to reiterate RLE assessment in the South Asian region for supporting mountain conservation. This is where the RLE-based assessment would be a much-needed tool and approach to understanding the present status of ecosystem health for effective and efficient protection of critical biodiversity areas achieving target-oriented conservation goals.

3 High Conservation Value Mountain Ecosystem: Strength, Weakness, Threats and Opportunities for RLE

3.1 *Hindukush* Himalayas

More than 35% of the world's population, directly and indirectly, are benefitted from the resources and ecosystem services of the HKH region (Kandel et al. 2021). The HKH spans over six countries from Afghanistan to Myanmar across Pakistan, India, Nepal, China, Bhutan and Bangladesh. While it covers the whole of Bhutan and Nepal, some Himalayan parts of the other six countries fall under the region. Ten major river systems originate from the region that holds the largest reserves of ice outside the poles. In terms of biodiversity and protected areas, the region has four global biodiversity hotspots with around 81,000 floral species, 15,000 faunal species, 33 key mammal species, flagship species, such as tigers, snow leopard, clouded leopards, rhinoceros balancing the food web, more than 60 global eco-regions, around 330 important bird and biodiversity areas, and high endemism. The HKH region, with almost 100 leading languages, is also a source of diverse cultures, languages, religions, and traditional knowledge systems that are highly influenced by the natural ecosystem (Chettri 2014). In terms of dependency, around 240 million people are directly dependent on the HKH region for their lives and livelihoods, and around 1.9 billion people for water, food, energy, and various other regulating services (Rasul 2014; Dhyani and Dhyani 2016b; Rasul et al. 2019). The HKH region is highly fragile, sensitive to loss of biodiversity and ecosystems from multi-dimensional drivers of environmental, social, and economic issues interlinked to impact at diverse Spatio-temporal scales. Land use and land cover change, overexploitation, pollution, invasive species, and climate change are the major environmental drivers (Wang et al. 2019). Demography, socio-cultural structures, and institutions with inequality and rapid economic growth with infrastructure development decoupled from the environment and proper holistic planning are the major socio-economic drivers. Among all, HIMAP (2019) highlighted climate change as a mega driver of loss for the region, and even an increase of 1.5 degrees of temperature will be highly adverse, bringing a long-lasting impact on the region (Krishnan et al. 2019; Sabin et al. 2020). Despite being net positive for carbon stocks and the happiest nation in the world, deforestation for various development purposes, increasing hydropower projects, agriculture expansion, and intensification, mining and quarrying for infrastructure development, and land degradation by timber harvesting, firewood, forest fire, and livestock overgrazing are the major drivers threatening the ecosystems in Bhutan, as found in a study prepared for REDD + (Bruggeman et al. 2016). In the last 80 years, a 1-m shift in the tree line and vegetation across the region has been observed (Dhyani et al. 2018, 2020b). Global warming with increased glacier melting is a huge threat for enhancing the frequency and intensity of frequent and long-term disasters in the region. Since 1910, there has been steady progress with 545 protected areas in the region. Targets of the convention on biological diversity assessments have been achieved quite well. Bhutan has exceeded target 11 with 55.39% of protected areas, and Nepal follows with 23.39% of protected areas (Rawal and

Dhar 2001; Dunn et al. 2016). China and India are forerunners in the progress and success achieved so far, but there is a growing need to focus on science-policy practice and advocacy for enhancing the outcomes from long-term conservation efforts. There is a need for urgent attention in managing the culture of expansion and settlement in the tropical forests along foothills and temperate forests in the inner valleys. River valleys are pressed by huge settlements, which are expanding and posing a threat to the watershed management. Tourism and related industries, agriculture intensification, and increasing pressure on high altitude wetlands are further increasing the threat to natural and high value but sensitive ecosystems (Areendran et al. 2020).

3.2 Eastern Himalayas

Accelerated pressure on forest ecosystems of the Eastern Himalayas poses threats and concerns, particularly as this has changed human–nature relationships over the millennia. The biodiversity hotspot in IHR, Eastern Himalayas, has an extension of approximately 2.415 km from Central Nepal to North–West Yunnan in China with an area of 524,190 sq. km. Three global biodiversity hotspots, the Himalayas, Indo-Burma, and mountains of South–West China, are part of the region. About 10,000 plant species, 30% of which are endemic, 977 species of birds, 300 species of mammals, 269 freshwater fishes, 176 reptiles (30% endemic), 105 species of amphibians (40% endemic) are found in this rich biodiverse Eastern Himalayan biodiversity hotspot that is home to flagship mammal species, such as tigers, rhinoceros, elephants, snow leopards, and clouded leopards (Basnet et al. 2019; Kandel et al. 2021) The cultural diversity of the region is equally rich because of the heritage of indigenous people and local communities (Dasgupta et al. 2021). The major pressures on the regional forest ecosystems come from forest degradation, deforestation for developmental projects, hunting poaching, followed by the unsustainable and illegal trade of valuable threatened wild species of flora and fauna (Peros et al. 2021). Illegal logging, deforestation, increasing forest fire incidences are alarming. The West Khasi Hills of Meghalaya, with the richest forest cover of the region, attracts the highest illegal logging and also the highest rate of migration. Commercial plantations (tea, rubber, areca nut, oil palm), encroachment for settlements and *jhoom* cultivations, timber and fuelwood collection, overgrazing, and diversion of the forest for infrastructure are degrading the ecosystems (Palit 2007; Sharma et al. 2012). Poverty can be a hidden driver of biodiversity loss; still, one cannot deny customary hunting and rat hole mining (in Meghalaya), which have further degraded the ecosystem and affected the flow of ecosystem services for human well-being (Majaw 2015). The major concerns for the region are rampant loss of biodiversity, diminished ecosystem services, drying up rivers and natural springs because of springshed degradation and fragmentation, reduced livelihood opportunities for forest-dependent marginalized communities, land degradation reducing primary productivity, land-use change from forests to scrubs, and grasslands, enhanced migration to cities for education and livelihood opportunities.

3.3 Central Himalayas

The Central Himalayas as fragile and extremely vulnerable to geophysical and meteorological factors that have always been prone to natural and human-made disasters, such as floods, landslides, forest fires, and high magnitude earthquakes (Dhyani and Dhyani 2016a; Somvanshi 2021). As the frequency of natural disasters has increased in the region in the past three decades, short-sighted economic development coupled with environmental degradation and natural resource depletion will further add to the socio-economic vulnerability and enhance the drudgery of local communities. Disaster risks will further enhance social insecurity, loss of human life, damage and loss of property, and other larger economic losses. The Himalayan Tsunami or Kedarnath crisis as the coupled disaster incidences were termed in 2013, affected the larger part of the state by floods from widespread and excessive rain due to cloud bursts and glacial lake outbursts in the upper Himalayas, resulting in massive landslides that led to the loss of more than thousands of lives and unforeseen damage to tourism infrastructure and property. Disasters are known for their negative impact on economies and stimulate inequalities in health, education, and infrastructure access, increasing the social–economic vulnerabilities among and drudgery of women and marginalized local communities (Dhyani et al. 2013b) (Fig. 3).

3.4 Western Ghats

Recognized by UNESCO as one of the important biodiversity hotspots, these hill ranges are considered as water tower is the source of numerous rivers. Since the mid-eighteenth century, the region has undergone a major landscape transformation and is subjected to high anthropogenic pressure due to the rise in population density, and about 40% of original vegetation was converted or lost (Gadgil et al. 2011). This region has been subjected to degradation of social capital and imposing excessive, unnecessary environmental damage in the process. The extensive wasteful road network, intensiveness of agriculture, mining, new township development, encroachments, intensive tourism, damaging topsoil, drop in genetic diversity, and invasive species are the major threats to the ecological balance of remaining natural ecosystems in this mountain range (Gadgil et al. 2011). Due to the changing climatic dynamics across the Western Ghats, particularly southern regions, the unprecedented rain and

Fig. 3 Wide spread socio-economic vulnerability as one of the hidden driver has largely affected the health and sensitivity of natural forest, alpine and grassland ecosystems at various altitudes

associated landslides and floods led to damage to ecosystems and infrastructure and the loss of lives and livelihood. Nearly 341 landslides were reported from 10 districts in Kerala, with a total loss to the tune of USD 3.8 billion during the torrential rains in 2018 (PDNA 2018). Even though the natural disaster caused by this heavy rain was a short-duration event, it has caused severe damage leaving a long-lasting impact on the forest ecosystems in this region (Deepu et al. 2020). It is warned that the Western Ghats will lose 33% biodiversity by 2050 due to climate change (Kulkarni 2021). The concerns raised by the anthropogenic pressure and changing climate emphasize the urgency of conserving the Ghats and sustainable use of its resources.

3.5 Eastern Ghats

The forests in the Eastern Ghats are a source of a variety of products having a potential output for trade, subjecting them to over-exploitation. The destruction of natural habitats by humans is the greatest threat to the biodiversity of the Eastern Ghats. Increasing tribal population and shifting cultivation, clearing vast fertile land tracks, leads to a substantial decline in floral diversity. Change in land use pattern due to land conversion for plantations and growing fodder for cattle etc., are pushing flora and fauna to threatened categories. Climate change and associated changes in monsoons and forest fires, both natural and induced, have largely influenced the microclimate, making it unfavorable to the flora and efficiency of pollinators. Linear intrusions in the form of power lines, roads, rise in urbanization, deforestation activities, and over-exploitation of minerals in a non-resilient manner are affecting this region's topography, and the entire area has lost its ecological balance (Reddy et al. 2013; Sundararaju 2019). All these contribute to the decline in the diversity of keystone species, invaluable bio-rich features and threaten the ecosystems. Only an effective strategy involving the local people for the eco-development of this region can protect the flora, fauna, and other natural resources of Eastern Ghats.

The conditions of other mountain systems in South Asia, such as the Salt range, Spin Ghar, Alagalla Mountain Range, etc., are also not so different from those discussed above. Since these hill ranges are not so rich in diversity, they received less attention to understand their contributions to ecological balance and are facing accelerating environmental and cultural decline.

SWOT analysis showed that the biodiversity and ecosystems in the region are affected by diverse direct and indirect drivers. Emphasis should be given to using hybrid knowledge frameworks that support the integration of updated scientific–technological tools and promote and endorse mainstreaming of the indigenous knowledge systems present in the region prevailing with hundreds of indigenous and local communities. For building an environment of a holistic approach towards management and conservation of the landscape and harnessing ecosystem values following nature-based solutions that support climate-sensitive restoration (Dhyani et al. 2020a, 2021) (Table 1).

Exploding population and unsustainable overdependence on natural resources coupled with the impact of climate change is degrading the health of ecosystems in the mountain systems. Ecosystem health assessment through an RLE approach of these systems helps to understand the trade-offs between conservation and use of resources and can support negotiations across spatial and temporal scales and policy imperatives to address the issues. This will also help in reducing the gap in knowledge on the vulnerability of mountain ecosystems to climate change.

While RLE can help assess the evidence-based ecosystem health and risk, collaboration of the state and national disaster management authorities, district disaster management centers, and the National Institute of Disaster Management is needed to scale up disaster risk reduction.

4 Relevant Ecosystem and Biodiversity Initiatives in the Region

The Transboundary Landscape Program of ICIMOD, aiming to conserve and manage natural resources for enhancing livelihoods of vulnerable mountain people through social and ecological resilience from NbS, is one major example (Ojha et al. 2019; Kotru et al. 2020). National Mission on Sustaining Himalayan Ecosystem (NMSHE) is another proactive and important mission by the Government of India. The National Mission for Sustaining the Himalayan Ecosystem (NMSHE), under the National Action Plan on Climate Change (NAPCC) aims to facilitate the preparation of appropriate policy measures and time-bound action programs to sustain ecological resilience and ensure the continued provisions of key ecosystem services in the Himalayas. To achieve six task forces has been set up by the Department of Science and Technology, India. The program focuses on innovative livelihood options, ecosystem management, protected area conservation through corridor management and connectivity, regional cooperation, better governance supported by long-term research and monitoring, and cross-country regional collaboration in sharing challenges and transboundary management for achieving Sustainable Development Goals (SDGs) together.

Major transboundary flagship programmes of Kailash Sacred Landscapes (KSL), Hindukush-Karakoram Pamir Landscapes (HKPL), Kanchenjungha Landscape (KL) and HI-LIFE focus on grounded issues to make lives better through innovative solutions and socio-ecological resilience (Sharma and Chettri 2005; Shakya et al. 2021). The

Table 1 SWOT analysis to understand the relevance of ecosystem health assessment using RLE approach for high conservation value ecosystems in South Asia

Strengths	Weakness
• The richness and representativeness of the forested landscapes and riverscapes • High biodiversity and high conservation value ecosystems • Uniqueness or in incomparable values in case of endemic species, specific habitats (e.g., wetlands, timberlines), special ecosystems (e.g., alpine meadows, cold deserts, and mountain agro-ecosystems) • Traditional and Indigenous knowledge systems	• High dependence of local people on the natural ecosystems for their subsistence requirements • Marginalized and poverty-ridden local socio-economic conditions • Poor management with less and inappropriate community involvement • Absence of holistic understanding of the fragility of mountain ecosystems • Inadequate knowledge base on diverse subjects and issues
Opportunities	**Threats**
• Huge terrestrial and soil carbon stock • Diverse ecosystems and biodiversity elements • Water tower for the region	• Land degradation due to increasing commercial tourism • Rampant harvest of high-value medicinal, aromatic wild edible plants • Increasing human-induced pressure from urban sprawling and infrastructure build-up • Habitat loss, unscientific use and overharvesting, and • Increasing peoples' apathy (Pandit et al. 2014) • Climate change, global warming, glacier melting • Enhanced invasion of exotic species (Xu et al. 2019)

Global Observation Research Initiative in Alpine environments (GLORIA) was started given the demand for long-term observations for understanding the impacts of climate on high mountain ecosystems, observation of ecosystems is a source for informed knowledge about environmental change (Grabherr et al. 2000). Following GLORIA standard design of Multi-Summit Approach Long-term Ecological Monitoring (LTEM) sites were established in Western Himalayas (Chandra Sekar et al. 2017). Similar sites are also established across eastern Himalaya, in Tibetan Autonomous Prefecture (TAP), Bhutan and Nepal. They cover a range of ecotones and collects an abundance of quantitative data that can be used to monitor the effects of Himalayan climate change on alpine vegetation (Salick et al. 2014).

SECURE Himalaya, funded by the Global Environment Facility (GEF), ensure sustainable management of alpine pastures and forests and conservation of locally and globally significant biodiversity, land, and forest resources in the high Himalayan ecosystem with a major focus on eradicating poverty. For documenting the threats posed by retreating glaciers WWF is handling a project Himalayan Glaciers and Rivers Project and Climate witness project to understand the potential environmental crisis. The information from this programme is envisaged for planning effective management with community participation. Project International Deep Profiling of Tibet and the Himalaya (INDEPTH), started in 1990s, is for having a better understanding of the geological structures and tectonic movements of the Himalaya–Tibet region using deep seismic reflection profiling for geophysical and geological studies.

SHARE-Asia (Stations for High Altitude Research in India) (https://himalayanvoices.org/?q=resources/projects/category/display/597) is an initiative by the Ev-K2-CNR Committee for a network through the Himalaya–Karakorum range for studying meteorological and climatic parameters, atmospheric chemistry, glaciology, high altitude limnology and paleo-limnology. There are also efforts to secure the conservation of priority site outcomes (key biodiversity areas) in the Eastern Himalayas through the support of CEPF.

The Critical Ecosystem Partnership Fund (CEPF) developed the ecosystem profile of the Western Ghats, which provides an overview of the causes of biodiversity loss, describes current institutional frameworks and investments for conservation, and outlines strategic directions that can be implemented by civil society to contribute to the conservation of biodiversity in the hotspot (CEPF 2007). As an initiative for reviving socio-ecological landscapes for biodiversity conservation and climate change adaptation, Durrell Institute of Conservation and Ecology, University of Kent along with local NGOs are making conservation remunerative to local people in the Northern Western Ghats through the Darwin Initiative since 2013, implementing the first FairWild certification in India for Haritaki and Bibhitaki fruits (Makita 2018). The rainforest restoration project by Nature Conservation Foundation since 2001 in association with major plantation companies and the Tamil Nadu Forest Department, is working on the restoration and protection of rainforest fragments on the Valparai plateau, Anamalai Hills of Western Ghats. Occasional programmes at the local scale are also seen in other mountain ranges in South Asia; however, there is a lack of initiatives addressing the hill ranges as a single unit.

5 Capacity Building of Actors for RLE

RLE as an ecosystem risk evaluation tool to assess ecosystem health has been developed with a follow able protocol and criteria to assess the relative risk of ecosystem collapse (Rodríguez et al. 2012; Sato and Lindenmayer 2018; Bland et al. 2019). In addition, RLE provides an understanding of the causes and pathways of changes in ecosystems that are based on the severity of threats or the most compromised processes of an ecosystem (Lindenmayer et al. 2016; Lindenmayer 2020). RLE has been used extensively across diverse ecosystems of the world and has the potential to serve as a fundamental basis for designing need-based and evidence-based strategies to abate and avoid risks for sensitive and fragile mountain ecosystems. There is sound evidence to support that RLE functions better at a national or continental scale than at a sub-national or regional scale. This has not been possible in many instances and single large ecosystem health has already been assessed by RLE. For example, Sunderbans National Park, where RLE was found successful for ecosystem health assessment (Sievers et al. 2020). RLE approach is considered beneficial in the context of climate change and can work beyond national borders or continental borders, or even eco-regions, and that is what makes it an appropriate tool to assess ecosystem health in mountain chains with a transboundary presence (Keith et al. 2013). RLE also provides an excellent opportunity to share crucial information and relevant data on different mountain ecosystems and the threats, as well as drivers of biodiversity loss for linking them with the global ecosystem topology. Previous mountain ecosystem assessments in other parts of the world can serve as the basis for South Asian assessments by leveraging available information (Clark et al. 2015; Williams et al. 2015; Chen et al. 2020; Murray et al. 2020). Land use planning, improvement of governance and livelihood, and macro-economic plans that is how RLE can help prioritize funding for conserving the identified ecosystems using appropriate restoration approaches and can also help to realize and localize UN Sustainable Development Goals (UN SDGs) along with international restoration conservation targets viz. UN Decade on Restoration (2021–2030);

Post 2020 global biodiversity framework, Bonn Challenge, Nationally Determined Targets and land degradation neutrality targets if judiciously used by governments (Fig. 4).

In the process of carrying out RLE, ecosystems are assigned two ordinal categories of risk from 'least concerned' to 'collapsed'. Depending on five different assessment criteria, two of these are around the distribution of ecosystem decline or restriction in the area with an elevated risk of collapse and two condition-based criteria the degradation or disruption of biotic processes causing the inability to support the key biota (Rodríguez et al. 2012; Keith et al. 2013; Sato and Lindenmayer 2018). With sufficient data availability, a quantitative risk analysis is possible, which gives information on the more complex interactions of an ecosystem. Each of these criteria is assessed against different time scales, a historical time scale from 1753 to the present, the recent past (last 50 years), and into the future (the next 50 years). The assessment process is preceded by a diagnostic phase, which involves understanding the key functions of the ecosystem, drivers of loss, and collapse. RLE identifies the ecosystem functional conduits and describes them based on the critical biotic or abiotic features and interactions and processes underpinning those ecosystems (Lindenmayer and McCarthy 2002; Lindenmayer et al. 2016; Beck et al. 2020). Through this diagnostic process, the RLE link features ecosystem services and human activities that in turn can help to inform conservation planning and land management policies to support good conservation and better livelihood options and opportunities (Lindenmayer 2020). The diagnostic process is complex but crucial for shaping the entire assessment in determining the usefulness of the assessment. The assessment units are defined and conceptualized using the global ecosystem topology, which provides a consistent ecosystem framework that is hierarchical and groups together ecosystem functions based on traits, common drivers, common threats, and common indicators. These generalizations can be further tailored to suit more national and local ecosystems. The global ecosystem topology further facilitates translation across existing topologies, leveraging data and information from past national level or regional level classifications (Rodríguez et al. 2012; Keith et al. 2013; Bland et al. 2019). In one of the Himalayan nations, Myanmar, RLE-based assessment is guiding the development of an ecosystem classification scheme previously absent (Murray

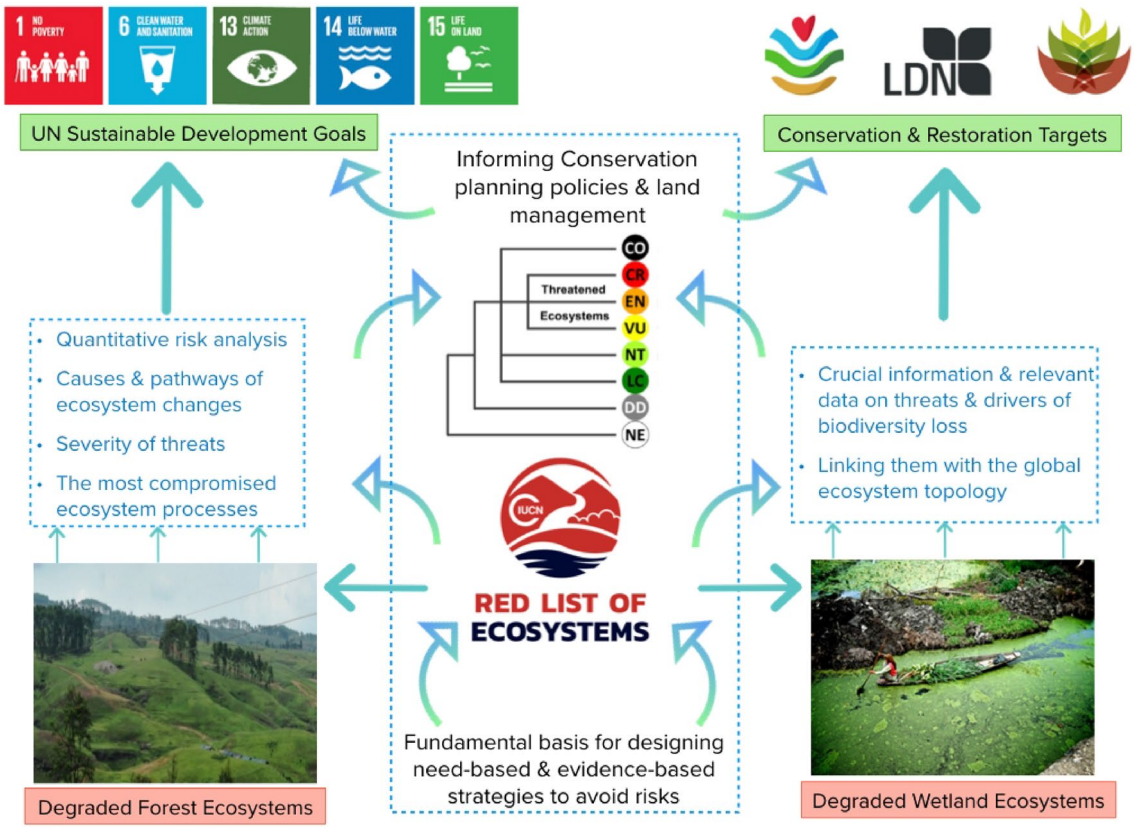

Fig. 4 Red list of ecosystems for designing need-based and evidence-based strategies for fragile mountain ecosystems in South Asia *(RLE threatened categories depicted are CO for Collapse, CR for Critically Endangered, EN for Endangered, VU for Vulnerable, NT for Near Threatened, LC for Least Concern, DD for Data Deficient and NE for Not evaluated)*

et al. 2020). For the first time, the country was systematically mapped or described through the assessment. The Myanmar assessment was a partnership effort between NGOs, government, and researchers. Over 2 years, the systematic assessment, using existing as well as new data, resulting in mapping different ecosystem components as the first national ecosystem inventory. The assessment highlighted the data gaps and the areas with a need for data collection. The RLE assessment of mountain ecosystems of Myanmar might be particularly useful for similar assessments in South Asia, especially for the Hindukush Himalayas and the Western Ghats having important biodiversity hotspots followed by the Maragala Mountain Range and other important mountain chains in the region. The biotic and abiotic assessments can aid CBD reporting, the development of protected area networks, and the identification of key biodiversity areas that require conservation priority. They can also help raise awareness about human dependence on natural capital and the trends and status of ecosystems, making the RLE highly valuable at even a local scale. Such assessment will also be a relevant regional contribution to a post-2020 global biodiversity framework to be negotiated in the CBD Convention of Parties (COP) at Kunming in 2022. This will also help achieve the targets of the UN decade on restoration (2021–2030) (Fig. 4). This process can be a fruitful basis, providing fundamental understanding for planning and collaborating with diverse agencies and organizations for the ecosystem health assessment of mountain areas, especially the Himalayas in South Asia. When we look into the RLE in Australia, it has largely been in partnership between government and researchers that support each ecosystem assessment. Expert elicitation workshops, literature reviews, and inclusion of Australia's national vegetation classifications into the assessment have helped the country work on evidence-based restoration and conservation planning. This example despite being from a very different geographical context is very relevant to be cited here to share how relevant it is to enhance cooperation of government with academics and scientists to bring better insights from RLE that can be well taken up by policymakers for appropriate policy formulations and their enforcements. Compilation of spatial database from government vegetation mapping with expert augmentations, threatened species habitat mapping, unspecific ecosystem mapping from researchers, etc., can help to explain how climate change coupled with land-use changes followed by other direct and indirect drivers of biodiversity loss will manifest in diverse systems, viz. alpine shrublands, meadows, peatlands, as well as alpine streams. However, the Himalayas and the Hindukush region fall under different countries in South Asia. Hence, cooperation among different nations is also crucial and necessary to implement an RLE-based conservation approach in this region. The RLE can be an excellent tool also to catalyze investment for further data collection to inform conservation planning and policies by amending and filling data gaps while taking inspiration from the available plethora of literature and RLE available from diverse geographies and ecosystems.

6 Key Data Gaps, Priorities, Collaborations, and Knowledge Partners

There is a need to understand deep histories of human settlements and human interventions for mountain landscapes, besides deep ecological histories, as these systems have been intruded with human interventions across history. Partnerships across local, regional, national, and international scales are key for the conservation of mountain ecosystems and for developing resilience and sustainability. The private sector may be recognized as a key player in planning and implementing assessments and solutions. The majority of the pressure on mountains comes from outside (demand for raw material, water, clean air, and energy), which is often connected to economies. The tremendous number of solutions that local communities can offer comes from their rich traditional ecological knowledge base. It would be a missed opportunity to ignore the knowledge that these communities have and to preserve that. Not only should a compendium of such solutions be made, particularly from the IUCN perspective of Nature-based Solutions, but there should be efforts to mainstream these solutions in mountain conservation and restoration. It is necessary to recognize transboundary issues related to collaborative efforts to conserve ecosystems, biodiversity, culture, and traditional heritage. In many scientific panels, it has been difficult to discuss these, but politics poor governance, and lack of clarity may often lead to disputes and enhanced long-term conservation challenges. One must recognize that the degradation of mountain systems, has a direct implication and long-lasting impact on the survivability of the plains and the water security of the entire region. This should be highlighted in terms of the economic value that is directly contributed by an unrestricted flow of diverse ecosystem services. There is a need to showcase the clear existing link of human well-being with the health and well-being of mountain ecosystems in the region. It is very clearly recognized how quickly flash floods and the ecosystem resilience of mountains affect low-lying communities and areas. This needs to be highlighted not only as a national but also regional and international priority area for research and financial support. There are hundreds of models available on climate change, including symmetry models, simplified models, and the latest generation of climate models. The common thread shared among all is that the kind of temperature rise predicted in the Hindukush Himalayan region is more severe than what has been witnessed. The future probably will be completely different from anything that has been

witnessed for this very reason. Emphasis should be placed on using advanced technologies for better policies to achieve socio-ecological resilience in the coming decades. However, there are challenges regarding data availability, especially long-term climate data in case of disasters, and the need to address them through satellite data to fill data gaps for modeling scenarios 30–50 years ahead. For effective policy planning, civil society engagement, a future scenario supported by advanced tools is vital. In this regard, IUCN tools are extremely valuable and should be facilitated by the active support and involvement of IUCN without much delay. The key data gap for ecosystem services is health assessment and an inventory, while that for mountain regions, especially Hindukush Himalayas is presented in Table 1. We need to promote not only a comprehensive inventory of ecosystem services that identify the larger, direct, and indirect benefits and values of ecosystem services, mega drivers of loss, trends, and scenarios to plan governance approaches appropriately. Local communities are to be included as local parties in terms of decision-making and preservation activities, which can help in transferring the indigenous community knowledge and practices in the governance system. Transboundary cooperation is needed among South Asian nations and stakeholders, such as governments, NGOs, academia, scientific organizations to enhance South Asian Regional Cooperation (SAARC) for mountains. Furthermore, many ongoing transboundary initiatives in mountain areas of the region can be strengthened and supported.

7 Potential Mitigation Measures and Future Research Dimensions

It is high time for shifting focus on the decline of glaciers in the Himalayas and associated impacts on rivers and socio-ecological processes. For a better understanding of the ecosystem health and change in community dynamics in forest ecosystems and freshwater ecosystems, permanent observation plots should be marked across the mountains. Promoting mainstreaming and involvement of traditional ecological knowledge systems for community-based management of these pristine mountain chains. Transboundary cooperation should be strengthened through sharing of information, know-hows including coordinated efforts for a better understanding of the Himalayan ecology. RLE assessments can facilitate cadastral survey creating data for efficient land use planning and restrictions on land-use changes, land degradation, deforestation, and other drivers. Creating awareness about ecosystem services with particular emphasis on water and forest linkages is necessary to mitigate land-use changes. Holistic planning for poverty reduction and nature-based employment generation is crucial for attaining the SDGs but that can be simultaneously achieved if governments show their commitment to conserving the rich mountain ecosystems enhance regional cooperation for ecosystem health assessments.

8 Conclusion

'Business as usual' can no longer be considered an option for the many fast degrading mountain areas across the region as few have been highlighted in the paper. There is a need to fill in the data gap through enhanced partnerships, multi-stakeholder participation by involving private sectors, civil society cooperation, local communities, and recognizing indigenous and local knowledge systems for creating options and opportunities. There are several successful examples from where regional cooperation lessons can be learned and endorsed. A few of them include cross-border Tiger conservation, Snow leopard conservation, Kailash Sacred Landscape program, and Kanchendzonga conservation for effective transboundary collaboration and implementing diverse NbS approaches for supporting and ensuring the well-being of local mountain residents. It is very clear that due to ongoing climate change coupled with many direct, indirect, and hidden drivers, mountain biodiversity, ecosystems, and ecosystem services will be facing more unforeseen threats like never before. Moreover, the mountain communities are already bearing the brunt and facing extreme events and the intensity of them is projected to enhance in the future will further affect ecosystem services supply and may also enhance the risks. Regional cooperation involving diverse stakeholder groups needs to discuss and find ways for conserving mountain biodiversity and restoring ecosystem health. Hence, ecosystem health and risk assessment of mountain ecosystems in South Asia, especially initiating from priority mountain areas and ecosystems and extending to lesser researched and explored chains. Conservation of many of these mountain chains spanning multiple nations, supporting millions of species and residents is crucial. Prioritizing and funding RLE in the region can avoid ecosystem collapse or reverse hidden factors leading to the collapse of high conservation value mountain ecosystems. RLE tools can help researchers to facilitate ecosystem assessment and advocate governments for sustainable conservation and management of biodiversity and ecosystem services for posterity.

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Declarations

Conflict of Interest The authors declares that they have no conflict of interest.

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