frontiers | Frontiers in Conservation Science

TYPE Original Research
PUBLISHED 02 September 2025
DOI 10.3389/fcosc.2025.1663322

OPEN ACCESS

EDITED BY
Anurag Dhyani,
Jawaharlal Nehru Tropical Botanic Garden and Research Institute, India

REVIEWED BY
Junaid Ahmad Magray,
University of Kashmir, India
Abhishek Chandra,
University of Delhi, India

*CORRESPONDENCE
Indra D. Bhatt
id_bhatt@yahoo.com
Shreekar Pant
shreekarpant.2@gmail.com

RECEIVED 10 July 2025
ACCEPTED 13 August 2025
PUBLISHED 02 September 2025

CITATION
Negi VS, Pathak R, Dangwal B, Joshi RK, Airi S, Sekar KC, Pant S, Bhatt ID and Samant SS (2025) Biodiversity conservation and management through forest landscape restoration in the Western Himalaya, India. *Front. Conserv. Sci.* 6:1663322.
doi: 10.3389/fcosc.2025.1663322

Biodiversity conservation and management through forest landscape restoration in the Western Himalaya, India

Vikram S. Negi[1,2], Ravi Pathak[2], Bhawna Dangwal[2], Ravindra K. Joshi[2], Subodh Airi[2], K. C. Sekar[3], Shreekar Pant[4*], Indra D. Bhatt[2*] and S. S. Samant[2,5]

[1]Department of Botany and Microbiology, Hemvati Nandan Bahuguna Garhwal University (HNBGU), Pauri, Uttarakhand, India, [2]G.B. Pant National Institute of Himalayan Environment (GBP-NIHE), Almora, Uttarakhand, India, [3]Garhwal Regional Center, G.B. Pant National Institute of Himalayan Environment (GBP-NIHE), Srinagar Garhwal, Uttarakhand, India, [4]Centre for Biodiversity Studies, Baba Ghulam Shah Badshah University, Rajouri, Jammu and Kashmir, India, [5]Manaskhand Science Centre, Uttarakhand State Council for Science and Technology (UCOST), Almora, Uttarakhand, India

UN Decade on Ecosystem Restoration seeks to advance existing global commitments, including the Bonn Challenge, Aichi Biodiversity Targets, and Sustainable Development Goals (SDGs), to promote effective environmental management. In the Indian context, ecosystem restoration is vital in enhancing the well-being of nearly 700 million rural inhabitants who depend directly on land resources. Considering this, the present study evaluates three decades (1992–2024) of restoration efforts at the 'Surya-Kunj' model site in the central Himalaya. Restoration of the degraded land began in 1992 with the plantation of 172 multipurpose plant species, followed by gap-filling activities until 2014. The adoption of simple bioengineering techniques and interventions facilitated the restoration process. Among the planted species, 136 native Himalayan species showed better performance, with a success rate of 62% compared to 38% of non-native species; the overall survival rate was 52% in the restoration model. Most planted tree species are now naturally regenerating, with healthy populations of seedlings and saplings. The success of the restoration model is evident from the rich biodiversity now present at the site, including 100 medicinal plant species, >160 species of birds, >100 species of butterflies, 86 bryophyte species, and >30 species of lichens. Community participation has been a key focus, fostering local stewardship, sustainable resource use, and replicating restoration practices on private lands. The site is also a knowledge dissemination hub for school students, teachers, and the local community. To date, we have conducted about 62 conservation education workshops, engaging over 5331 stakeholders and students, and building their capacity on restoration and diverse conservation issues in the Himalaya. The 'Surya-Kunj' model demonstrates that integrating ecological principles with community involvement can yield a self-sustaining, biodiversity-rich site, offering a replicable framework for Himalayan landscape restoration.

KEYWORDS

ecological restoration, land rehabilitation, carbon sequestration, REDD+, people participation, ecosystem-based services

1 Introduction

Forests are home to 80% of the world's terrestrial biodiversity; globally, 1.6 billion people (nearly 25% of the world's population) rely on forests (IUCN, 2021), with most of them (about 1.2 billion) using trees on farms to generate food and cash (MacDicken, 2015). This is the reason that forests are emerging as a key arena of action at the forefront of major global initiatives, i.e., Sustainable Development Goals (SDGs) and Aichi Biodiversity Targets of the Convention on Biological Diversity (Adams et al., 2004). Forests regulate ecosystems and bio-geochemical cycles, support biodiversity and livelihoods, and help to contribute to sustainable growth (MacDicken, 2015; IUCN, 2021). However, deforestation and forest degradation due to environmental change and anthropogenic disturbances disrupt the ecological functions, diversity, and delivery of ecosystem services (IUCN, 2014; Díaz et al., 2019; Soh et al., 2019; Bhatt et al., 2020; Wani et al., 2022). Globally, more than 3.2 billion people have been affected by land degradation and deforestation. Global Assessment of Land Degradation and Improvement (GLADA) reported that 24% of the land is degrading, 23% of broadleaved forests, and 19% of coniferous forests have been degraded (Bai et al., 2008). This assessment further reported that more than 2 billion people directly depend on these degrading areas for their livelihood, therefore, making them most vulnerable. Halting the loss and degradation of forest ecosystems and promoting their restoration have the potential to contribute over one-third of the total climate change mitigation that is required by 2030, to meet the objectives of the Paris Agreement (Palita et al., 2011; Brooks et al., 2012; Bonn Challenge, 2019; IUCN, 2021).

Forest restoration is considered a critical strategy for conserving global biodiversity and climate change mitigation (Bastin et al., 2019; Chazdon and Brancalion, 2019; IUCN, 2021; Wani et al., 2025). Restoration of degraded, deforested, and fragmented land has been globally recognised as an effective strategy for achieving the goal of biodiversity conservation and climate change mitigation (Díaz et al., 2015; Bonn Challenge, 2019). Ecological restoration and mainstreaming of the concept of ecosystem services will be critical if global society is to move toward sustainability. It was well reported that the restoration is successful only through people's consultation and participation (Maikhuri et al., 1997; Negi et al., 2015; Iype et al., 2025). Large-scale failure of past efforts can be attributed to the lack of a participatory strategy to determine the essential needs of the local population and gain their cooperation (Meli et al., 2014; Wagley and Karki, 2020). Over the past two decades, ecological restoration, particularly forest landscape restoration (FLR), has increasingly been taken into consideration in decision-making processes and international studies, treaties, and conventions (Díaz et al., 2015; Bhattacharya et al., 2018; Bonn Challenge, 2019; Ashraf and Ahmad, 2024). FLR is considered worldwide as a powerful approach to recover ecological functionality and to improve human well-being in degraded and deforested landscapes (Sabogal et al., 2015; Brancalion and Chazdon, 2017; César et al., 2021). Ecosystem restoration is fundamental to achieving the Sustainable Development Goals (SDGs), mainly those on climate change, poverty eradication, food security, water, and biodiversity conservation (Aronson and Alexander, 2013; Bhattacharjee, 2020). This is the reason for declaring this decade (2020-2030) as the Decade of Ecosystem Restoration by the UN General Assembly.

Restoration of degraded land has been an essential activity on the agenda of the Government of India since the early 1980s, when India launched the Social Forestry Programme (SFP), followed by the more participatory Joint Forest Management (JFM) Programme. India joined the Bonn Challenge pledge in 2015 during the UNFCCC Conference of the Parties (COP) in Paris. Further, in the 'Delhi Declaration' during UNCCD CoP 14, India committed to the recovery of 26 million hectares of degraded land, and an additional eight million by 2030 (Bhattacharya et al., 2018; Bonn Challenge, 2019; UNCCD, 2019). Further, India has acted as an important stakeholder in shaping the mechanism of REDD+ (Reducing Emissions from Deforestation and Forest Degradation) by emphasising the role of conservation and sustainable forest management in mitigating carbon emissions (MoEF&CC, 2018). Among the world's mountains, the Himalaya regulates the hydrological cycle, sustaining high levels of biodiversity and human well-being (Rawal et al., 2013, 2021; Chettri and Sharma, 2016; Anjum et al., 2023). Forest degradation and deforestation are considered a common process in the Himalayan region, which needs immediate implementation of restoration programmes and their long-term monitoring (Pandit et al., 2007; Alexander et al., 2016; Chakraborty et al., 2018;

Negi et al., 2018a). Ecological restoration is an important tool for increasing biodiversity and carbon stock levels in human-altered ecosystems, which will help mitigate climate change impacts (Brudvig, 2011; Erbaugh et al., 2020; Jinger et al., 2023; Ali et al., 2024). Ecological restoration supports the plantation of native species for better survival and performance. Past studies reported that native species are ideal for restoring degraded forests/land due to their adaptability in a particular environment (Thomas et al., 2014; Lu et al., 2017). Therefore, the selection of plant species for the restoration programme is based on local demand and their eco-physiological attributes following past studies (Maikhuri et al., 1997; Negi et al., 2015). Further, the selection of bio-engineering (i.e., trenches, water harvesting tank, gully plugging, check dam), and measures for soil and water conservation for restoration were also highlighted in many studies. GBP-NIHE significantly contributes to environmental conservation and sustainability by developing restoration models in different parts of the Indian Himalaya. The present study attempts to (i) highlight the restoration activities at a successful restoration model, (ii) examine the impact of restoration activities on biodiversity conservation, and (iii) evaluate the social implications of ecological restoration in the western Himalaya.

2 Materials and methods

2.1 Study area

The restoration model developed was named 'Surya-Kunj', a Nature Interpretation and Learning Centre (NILC). This *ex-situ* conservation site was established as a functional restoration model in 1992 at the G.B. Pant National Institute of Himalayan Environment (GBP-NIHE). Initially, the entire study area consisted of degraded gentle slopes with few individuals of *Pinus roxburghii* and shrub species. However, through various rehabilitation and plantation programmes simultaneously, the site has emerged as a critical biodiversity-rich area. It is spread over 71 acres (28.73 ha) at an altitude ranging from 1100 to 1250 m asl. The area in between the habitation structure comprises various vegetation like Jalmalya (*Salix tetrasperma*), various species of Oak (*Quercus* spp.), Pangar (*Aesculus indica*), various species of *Bauhinia*, Mulberry (*Morus alba*), Silver oak (*Grevillea robusta*), Bottlebrush (*Callestimon citrinus*), Utis (*Alnus nepalensis*), Ghingaru (*Pyracantha crenulata*), Hisalu (*Rubus ellipticus*), Kilmora (*Berberis asiatica*), Deodar (*Cedrus deodara*), and many other trees, shrubs, and herb species. The plant species planted in the restoration model are predominantly western Himalayan elements, which have successively evolved into a refuge for various faunal elements strikingly having affinity with Palearctic and Oriental biogeographic regions.

2.2 Approach and methods

GBP-NIHE developed a practical approach to implement restoration programmes in the IHR and monitor their effectiveness. This includes (i) selection of a suitable site for restoration, (ii) analysis of the site to be restored for basic ecological parameters i.e., species richness, composition, and soil parameters, (iii) understanding the causes of degradation and deforestation, (iv) selection of suitable plant species based on eco-physiological attributes of particular species, (v) selection of appropriate bio-engineering measures for soil and water conservation, (vi) ensure pre-plantation activity, i.e., preparation of suitable pits and application of manure in these pits, (vii) people participation in restoration activities, (viii) ensure long-term monitoring of the restoration sites, and (ix) demonstration of successful restoration model for promoting sensitisation and conservation education.

2.2.1 Development of different demonstration sites

The species for the plantation were selected based on ecological and eco-physiological aspects of the site. *Quercus* spp., *Cinnamomum tamala, Bauhinia Purpurea, Celtis australis*, and *Aesculus indica* preferred large-scale plantations due to multiple usages. Preparation of suitable pits was completed six months before the plantation, followed by the application of manure to these pits. Protection of sites against open grazing and any disturbances was ensured through meetings with the nearby villages. The sites were protected against open grazing according to the agreed-upon terms and conditions of the Memorandum of Understanding (MoU) between the villages and the institute.

2.2.2 Development of simple techniques and interventions

Water for irrigation was identified as the key input needed for growth and improvement in site productivity, considering mountain terraces. Since the sites have acute water scarcity, low-cost polyethylene-lined underground water harvesting tanks were prepared at different locations for irrigation purposes. Bio-engineering measures like terracing, bunding, gully plugging, small check dams, etc., were developed to halt the ongoing process of soil erosion and improve the moisture content (Maikhuri et al., 2000; Negi et al., 2015). Further, staggered contour trenches were also developed for rainwater harvesting and to check soil erosion. Wastewater near the road site (1.2 km from the restoration site) was channelled to water harvesting tanks for irrigation purposes at the restoration model. A mechanism of collecting seeds of important species from this restoration site for gap filling through direct sowing or nursery development was the key strategy adopted in the restoration model.

2.3 Awareness and community involvement in the restoration model

Awareness was created among the villagers for large-scale plantation and restoration of degraded and abandoned land in the region through various programmes. To ensure active participation of the local community in restoration activities, labour work/wages are given to the nearby villagers for plantation and other activities. Further, the program facilitated regular interactions among scientists and villagers, establishing linkages with the community to transfer technical know-how on restoration activities. Further, these villagers have been given the right to harvest fodder biomass from the restoration site, mainly naturally growing grasses. After the development of the restoration model, the institute has also developed a Nature Interpretation Learning Centre (NILC) near the model to motivate students and teachers in conservation education. In the last three decades, the Institute has evolved a mechanism for informal biodiversity education in Uttarakhand through conducting several National Nature Camp Programmes (NNCPs) with schools (both government and private).

2.4 Vegetation sampling

The woody plant species (trees and shrubs) were sampled to study the impact of restoration on species composition and regeneration. Sampling was done in those areas where plantations were before 2001, and those sites are now naturally regenerating. Those areas of the restoration model where the plantation was done after 2002 for gap filling were avoided in sampling, as the height of trees nearly resembles saplings. All trees >30 cm girth size in the 8.5 ha area of the restoration model were tagged with numbered aluminium tags as follows for long-term monitoring (Negi et al., 2019). The circumference of each tree was measured, and species were identified using our taxonomic knowledge and with the help of field guides and floras. Digital photographs of some species were taken, preferably in the flowering or fruiting stage, for consultation with taxonomic experts to ascertain the identification of these species. A complete record of all trees growing in the restoration model has been maintained to monitor growth, biomass accumulation, and changes in other ecological attributes. In addition to trees, shrubs, saplings, and seedlings of tree species were also sampled in plots of 25 m^2 (5×5 meters) within a total of 54 plots (Rawal et al., 2018). The plots were laid out at every new encounter of previously unrecorded species in the sapling or seedling stage. Species accumulation curves were followed to ascertain sufficient sampling for seedlings, saplings, and shrubs.

Tree species with a girth size of 10-30 cm were considered saplings, and <10 cm were seedlings (Saxena and Singh, 1982). The total number of trees >30 cm girth size for each species was divided by the area of the restoration model (8.5 ha) to obtain the density of trees per hectare. Since it was not feasible to sample the whole restoration model seedlings, saplings, and shrubs, the mean number of saplings, seedlings, and shrubs per sampling unit was converted to their density per hectare. The regeneration status of tree species was determined based on the population density of seedlings, saplings, and adults (Gebrehiwot and Hundera, 2014; Wani and Pant, 2023). The status was categorised as (i) "Good" regeneration if seedlings > or < saplings > adults; (ii) "Fair" regeneration if seedlings > or ≤ saplings ≤ adults; (iii) "Poor" regeneration, if a species survives only in sapling stage, but no seedlings (though saplings may be < or ≥ adults); (iv) "None" or not regenerating, if species is absent in both sapling and seedling stages, but only found in adults; and (v) "New", if a species has no adults, but present in only saplings and/or seedling stages (Rawat et al., 2013; Negi et al., 2018b; Negi et al. 2024; Negi et al., 2025; Rawal et al., 2023).

3 Results

3.1 Plantation and species richness in the restoration model

About 190 tree species were planted during the last three decades in the restoration model - 'Surya-Kunj' (Figure 1). Among the species selected for plantation, 136 native species to the Himalayan region showed better performance than 54 non-native species. The success rate of native and non-native species was 56% and 52%, respectively. In terms of climatic affinities, 47.2% of tropical species and 57.6% of temperate species grew successfully in the restoration model (Figure 2). However, in the present study, a total of 125 woody species were recorded from the restoration model, including 98 trees and 27 shrubs. Among the trees, 74 species were in the adult stage (>30 cm circumference), whereas 02 species were only in the sapling or seedling stage (Table 1). The average tree density in the restoration model was 323 ind/ha, and the total basal area for trees was 23.8 m^2/ha. Species richness of shrubs was 26, and the density of shrubs was 5400 Ind/ha; dominant shrubs were *Rubus ellipticus, Pyracantha crenulata, Berberis aristata*, and *Rosa moschata*. The girth class distribution of trees reveals that this restoration site is highly dominated by trees with smaller girth sizes (30-49 cm). Trees >50 cm girth show a similar pattern of decrease in the number of individuals with increasing girth size. The regeneration status of trees in the restoration site varied for each tree species. It was found good for *Albizia procera, Aleurites moluccanus, Bauhinia retusa, Bauhinia variegata, Celtis australis, Cinnamomum tamala, Dalbergia sissoo, Engelhardia* spicata, *Euonymus hamiltonianus, Grewia oppositifolia, Ligustrum nepalense, Machilus duthie, Melia azedarach, Myrica esculenta, Neolitsea umbrosa, Pittosporum eriocarpum, Prunus cerasoides, Pyrus pashia, Quercus glauca, Quercus leucotrichophora, Toona serrata*, and *Toona ciliata* (Supplementary Table S1). Higher species richness and density of trees, with the dominance of small girth class and higher regeneration success in the site, indicate better progression in the future. *Pinus roxburghii* is the dominant tree species with a density of 144.1 trees/ha, followed by *Quercus leucotrichophora* (34 trees/ha) and *Grevillea robusta* (21.7 trees/ha). The maximum number of saplings was recorded for *Celtis australis*, followed by *Quercus leucotrichophora* and *Pyrus pashia*. However, the maximum number of seedlings was recorded for *Pinus roxburghii*, followed by *Celtis australis* (Supplementary Table S1). Many wild edible plant species support the diversity of birds in 'Surya Kunj' (Table 2).

3.2 Status of medicinal plants, lichen, and bryophytes

The institute has established a medicinal plants (MPs) garden in the 'Surya-Kunj'; this garden harbours over 90 species of medicinal

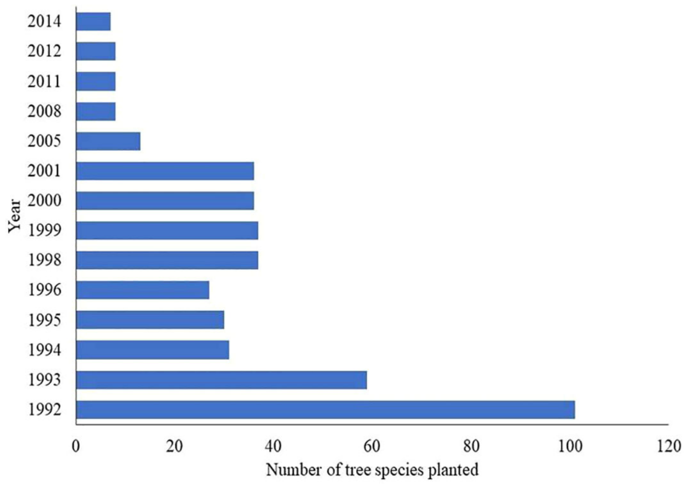

FIGURE 1
Plantation history in the 'Surya-Kunj' over the years.

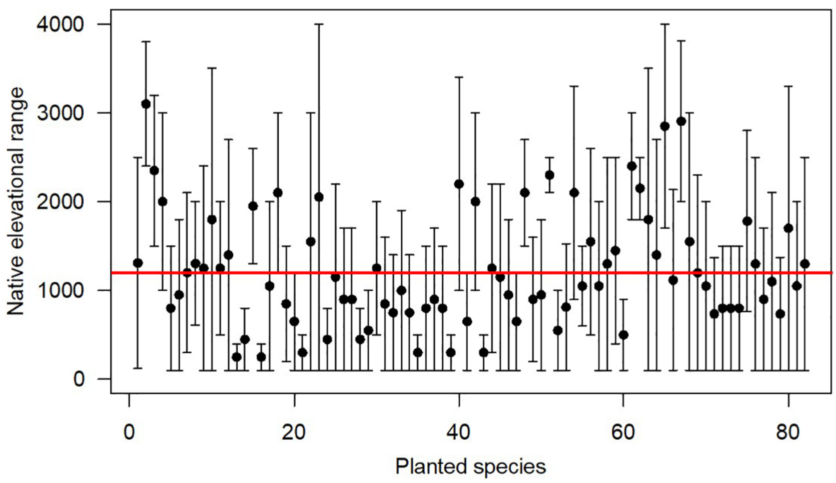

FIGURE 2
Native ranges of 88 successfully planted species in the arboretum depicting the mean, lower, and upper elevational limits of their native ranges (The Line in red colour represents the elevation of the study site to depict the comparative elevation range of the planted species).

value (Figure 3). These species include those of high value MPs, such as *Taxus wallichiana* (renowned for its anti–cancer properties), as well as highly threatened species like *Habenaria intermedia*, one of the Astavarga group (Table 3). Plants of Anti-cancerous (e.g., *Taxus wallichiana*), anti-diabetic (e.g., *Paeonia emodi*), anti-inflammatory (e.g., *Berberis asiatica*), anti-malarial (e.g., *Artemisia annua*), along with endemic threatened (ET) Himalayan MPs (e.g., *Podophyllum hexandrum*, *Meizotropis pallita*, etc.) are the main attraction of the garden. Several lichen species include *Bacidia* De Not., *Buellia* De Not., *Candelaria* A. Massal., *Caloplaca* Th. Fr., *Canoparmelia* Elix & Hale, *Chrysothrix* Mont., *Cladonia* P. Browne, *Dirinaria* (Tuck.) Clem., *Graphis* Adans., *Heterodermia* Trevis., *Hyperphyscia* Müll. Arg., *Lecanora* Ach., *Lepraria* Ach., *Parmotrema* A. Massal., *Phaeophyscia* Moberg, *Punctelia* Krog, *Pyxine* Fr., *Ramalina* Ach., *Usnea* Dill. ex Adans. and *Xanthoparmelia* (Vain.) Hale) have been colonised on various trees in different sites of 'Surya-Kunj'. About 30 lichen species were reported from 'Surya-Kunj' (Joshi et al., 2014). In all, 86 bryophyte species, including 14 thalloids, 11 leafy liverworts, 2 hornworts, and 56 mosses (Bhandari et al., 2019), were collected and identified from 'Surya-Kunj'. Out of these mosses, 34 turned out to be Acrocarpous, and 22 mosses were found to be Pleurocarpous. Amongst mosses, Pottiaceae, with 10 species, and Bryaceae, with 9 species, were the dominant families. Several thalloid, leafy liverworts and mosses were observed to be Gemmiferous.

TABLE 1 Comparison of tree richness and density between 'Surya Kunj' arboretum.

Parameter	Values
Adult tree richness	74
Tree sapling richness	25
Tree density (individuals/ha)	323
Tree basal area (m^2/ha)	23.8
Above-ground biomass (Mg/ha)	99.5
Above-ground carbon stock (Mg/ha)	49.5
Shrub species richness	26
Shrub density (individuals/hectare)	5600
Sapling density (individuals/hectare)	4880
Seedling density (individuals/hectare)	3040

TABLE 2 Various plant species that support the diversity of birds in 'Surya Kunj'.

Plant species	Fruiting time	Flowering time
Alnus nepalensis	November-March	September-October
Berberis asiatica	May-July	March - May
Rubus ellipticus	April-May	February-April
Pyracantha crenulata	June-September	April-May
Morus alba	June-August	March-April
Prunus cerasoides	December-February	October-December
Pyrus pashia	November – December	February-April
Melia azedarach	June-October	April-May
Callistemon citrinus	June-September	November-December
Ficus palmata	May-July	March-April

3.3 Diversity of birds, butterflies, and insects

Over the years, bird species richness at the restoration site has increased markedly (Figure 4). The first checklist from 'Surya-Kunj' documented 61 species in 2000 (Kothari et al., 2004). Subsequent studies added another 42 species to this list (Joshi and Negi, 2005; Palita et al., 2011). More recent surveys using the point count method have expanded the record, bringing the total to over 160 bird species (Joshi et al., 2016a) in the restoration model; the restoration model also supports various threatened birds (Table 4). The naturalisation of plants on the site has also helped provide butterflies with numerous host plants. About 100 species of butterflies have been reported from the site (Joshi et al., 2016b), also found during the evaluation (Figure 5). In addition, the plant species that are crucial for the insect life cycle and their proliferation have ensured favorable conditions and food base for many insectivorous birds. Bhatt et al. (2020) have reported 78 species of insects from the site (Figure 5).

3.4 Social implications and replication

Local participation and social inclusion were the key to our restoration model. The restoration model was developed with the participation of local people in the nearby villages. Their active participation has been achieved not only in the execution of the restoration programme but also in the adoption and extension of the restoration activities on their private lands. The institute ensures the right of resource collection and utilisation from the restoration site to the nearby villagers. In contrast, they protect the site from grazing and other means. A nursery of important plants was developed to fill gaps in the restoration site and supplement plant species for the local stakeholders. The nursery can produce over 50000 saplings of various native species and has been ensuring the distribution of saplings to various departments for restoration activities in the region. The bio-resources from the site (leaf litter) contributed to the preparation of composting, and villagers used grasses from the site to fulfill their fodder needs.

3.5 Promoting conservation education

Initially, the nearby village community was given training for awareness of biodiversity conservation and restoration through various programmes of the institute. Apart from informal meetings and discussions, 21 training programmes were organised to build the capacity of the villagers for biodiversity conservation through promoting restoration activities. Training and capacity-building programs are regularly organised to connect the students, teachers, and other stakeholders with nature. Awareness activities include celebrating national and international biodiversity conservation days, environmental management, and implementing the National Nature Camping Programme (NNCP) of the MoEFCC, Government of India. The Institute, over the years, organised 62 conservation education programmes in diverse aspects of biodiversity conservation and management. Over 5331 participants (4373 students and 958 teachers) from 822 schools/colleges participated in these conservation programmes. In addition, the site has become an important site for visitors, most importantly, school students, and a study site for researchers.

4 Discussion

Forest Landscape Restoration (FLR) emerged in 2000 as a novel approach to recover ecosystem services and strengthen human well-being in deforested and degraded areas (Sabogal et al., 2015; César et al., 2021). 'Delhi Declaration' during UNCCD CoP 14, India committed to bringing 13 million hectares of degraded land under restoration by 2020 and an additional 8 million hectares by 2030 is a challenge in the face of global climate change and rapidly increasing

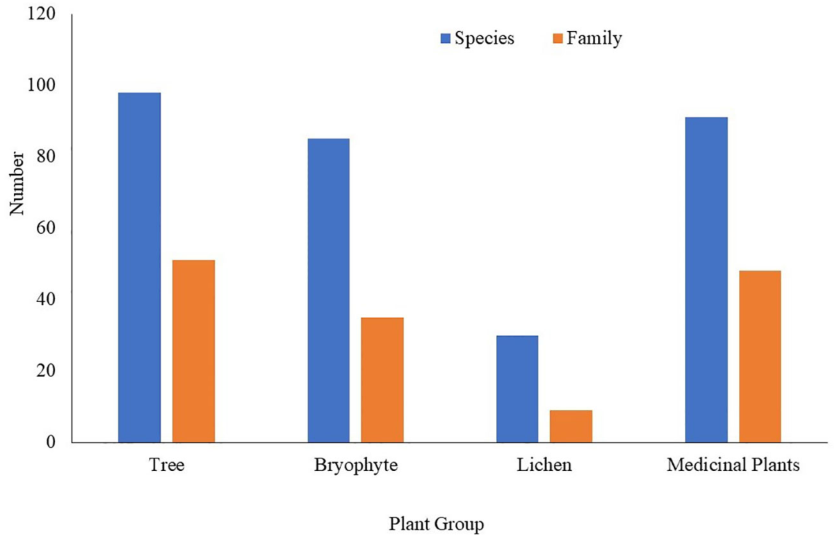

FIGURE 3
Status of tree, lichen, and bryophytes in the Restoration Model.

human population (Bhattacharya et al., 2018). However, to meet these targets, the successful restoration model with their community linkages and scientific inputs can become a candidate to accelerate restoration or the FLR process across the globe, particularly in the IHR (Bhattacharya et al., 2018; Bastin et al., 2019; Höhl et al., 2020; César et al., 2021). The successful restoration sites can contribute to Aichi Target 15 of the Convention on Biological Diversity, climate change mitigation, and the SDGs goal. Further, the role of forests as a carbon dioxide sink has received increasing attention since the adoption of the Kyoto Protocol to UNFCC in 1997 (Maniatis et al., 2019). It is well known that several restoration projects have been implemented under the FLR programme across the globe; this success depends on their monitoring and management. The success of past restoration projects remains poorly documented; this missed opportunity to learn from past experiences is essentially required for upscaling (Sabogal et al., 2015; Negi et al., 2022).

As a case, our restoration model has resulted in quantifiable improvement of the species richness, community composition, and carbon sequestration potential. Our study has provided an example of successful forest restoration in the Himalayan Mountain region, with 88 species successfully established with sufficient numbers of seedlings and saplings, which further supports that afforestation is an important measure for improving species composition, as also reported elsewhere (Guo et al., 2013; Osuri et al., 2019). Over the years, 'Surya-Kunj', which was a degraded slope, has been rehabilitated with around 190 species representing nearly 51% of the total tree species (372 species) of the western Himalaya (Bhatt et al., 2016). The present analysis showed regeneration in 88 species representing nearly 24% of total West Himalayan tree species, belonging to 61 families representing nearly 94% of West Himalayan tree families (Bhatt et al., 2016). Despite its extent, the family representation of tree species aptly reflects the site as an evolving restoration model of representative West Himalayan floral elements. People's consultation and participation were important components of our restoration model; this motivated villagers for plantation activities and created awareness for biodiversity conservation, as reported in past studies (Maikhuri et al., 2000; Negi et al., 2015). The impacts of the restoration model are seen as the villagers adopted plantation activities on their private farmlands, and also in community-managed abandoned land. The institute has up-scaled the restoration activities in other areas of the IHR through its Regional Centre, engaging the community (please see Bhatt et al., 2020). Further, the institute has developed a few specific techniques for restoration in the IHR, including Sloping Watershed Environment Engineering Technology (SWEET), Agroforestry Model, Silvi-Pasture Development, Contour Hedgerow Farming System, and Bio-Engineering Measures (Bhatt et al., 2020). Taking advantage of these interventions, people across the IHR are implementing them in the restoration activities.

Planting native species is recommended globally for ecosystem restoration and improvement in genetic diversity in a particular ecosystem (Budiharta et al., 2014; Wani et al., 2025). Although the difference in survival of native and non-native species is too low to impact the restoration's success in the present study. However, it is well known that native species are ideal for restoring degraded forests (Lu et al., 2017; Thomas et al., 2014; César et al., 2021). In addition, the ground layer of vegetation, particularly of shrubs, herbs, lichen, and bryophytes, was improved significantly in the restoration model (Joshi et al., 2014; Bhandari et al., 2019). Few endemic species like *Trachycarpus takil, Meizotropis pellita, Pittosporum eriocarpum, etc.*, are unique to the restoration site. This site also has all five species of Oak, i.e., *Quercus leucotrichophora, Q. semecarpifolia, Q. glauca, Q. floribunda, and Q. lanuginosa*, that are reported from the western Himalaya. The regeneration and recruitment in the restoration model were quite good for many species. Natural regeneration of tree species has started, as reflected by the presence of seedlings and saplings of

TABLE 3 Diversity of medicinal plants in 'Surya Kunj'.

Name of the plant	Family	Common name	Ethno-medicinal uses	Distribution (m asl)
Achillea millefolium L.	Asteraceae	Gandrain, Puthkanda	Diaphoretic, astringent, tonic	300-3500
Achyranthes aspera L.	Amaranthaceae	Chatkuri	Malarial fever, Mental disorders	1000-2200
Acorus calamus L.	Araceae	Bach	Dysentery, Mental disorders	1400-2300
Aesculus indica (Colebr. ex Cambess) Hook.	Hippocastanaceae	Khnor, Panger	Rheumatic pain, blood clotting	900-3000
Ajuga parviflora Benth.	Lamiaceae	Ratpatti	Fever, Worm infestation	1200-2800
Allium humile Kunth	Liliaceae	Dhun	Cuts and Wounds	3000-4500
Alpinia galanga (L.) Willd.	Zingiberaceae	Kulanjan	Heart diseases	1800-2200
Amomum subulatum Roxb.	Zingiberaceae	Badi Ilayachi	Chronic cough	300-1200
Angelica glauca Edgew.	Apiaceae	Gandarayan	Constipation, Gastritis	3000-3700
Artemisia annua L.	Asteraceae	Paati	Worm infestation	2200-3200
Artemsia capillaris Thunb.	Asteraceae	Marwa	Worm infestation	1200-2400
Asparagus racemosus Willd.	Liliaceae	Satawari	General debility	2000-2600
Berberis aristata DC.	Berberidaceae	Kilmorha	Diabetes, Gout	1500-2500
Berberis asiatica Roxb. ex. DC.	Berberidaceae	Chunchri	Anti-inflammatory, antidiabetic	900-2500
Bergenia ciliata (Haworth) Sternberg	Saxifragaceae	Silphoda	Kidney stone	1600-3200
Berginia ligulata (Wall.) Engl.	Saxifragaceae	Pashanbheda	Antidiabetic, Kidney stone	1600-3200
Bicschofia javanica Blume	Euphorbiaceae	Kanji	Toothache	300-1000
Boerhavia diffusa L.	Nyctaginaceae	Punarnava	Pain relief, liver diseases	300-1200
Centella asiatica (L.) Urban	Apiaceae	Brahmi	Blood purifier, Brain tonic	1200-2800
Cichorium intybus L.	Asteraceae	Kasni	Liver, gall bladder and kidney problem	300-1500
Cinnamomum tamala (Buch.- Ham.) T. Nees&Nees	Lauraceae	Tejpatta	Cough and cold	600-1300
Coleus forskohlii (Willd.) Briquet	Lamiaceae	Fiven	Kidney stone	1000-2500
Corylus colurna L.	Corylaceae	Bhotia badam	Cough and cold	2300-2900
Curcuma longa L.	Zingiberaceae	Haldi	Arthritis	800-1300
Cymbopogon jwarancusa (Jones) Schultes	Poaceae	Bhujir Ghas	Antibacterial	300-1400
Cyperus rotundus L.	Cypraceae	Motha	Analgesic	300-2400
Dalbergia sissoo Roxb. Ex DC	Fabaceae	Sheesham	Skin disorder	100-900
Diploknema butyracea (Roxb.) H.J. Lam	Sapotaceae	Chyura	Arthritis	300-1200
Elaeocarpus ganitrus Roxb. *Ex* G. Don	Elaeocarpaceae	Rudraksh	Diabetes, Blood pressure	400-1700
Euonymous hamiltonianus Wall.	Celastraceae	Agnyo	Herpes zoster, Anti-inflammatory	1600-2700
Ginkgo biloba L.	Ginkgoaceae	Gingo	Brain booster, Cancer, Asthma	2200-2800
Habenaria edgeworthii Hook.f. ex Collett	Orchidaceae	Vridhi	Aphrodisiac, appetizer, tonic	1500-3000
Habenaria intermedia D.Don	Orchidaceae	Ridhi	Aphrodisiac, appetizer, tonic	1500-3000
Hedychium spicatum Buch.-Ham. *Ex* Smith	Zingiberaceae	Van Haldi	diarrhoea, Asthma, Analgesic	1500-2600
Heracleum candicans Wallich *ex* DC.	Apiaceae	Patrala	Leukoderma, Cancer, Spasmodic	2200-3800
Heynea trijuga Roxb.	Meliaceae	Vanritha	Tonic	300-1500
Inula racemosa Hook. f.	Asteraceae	Pushkarmool	Cough, respiratory discomfort	1300-4500

(Continued)

TABLE 3 Continued

Name of the plant	Family	Common name	Ethno-medicinal uses	Distribution (m asl)
Mahonia jaunsarensis Ahrendt	Berberidaceae	Khoru	Fever	1950-2200
Malaxis acuminata D.Don	Orchidaceae	Jeevak	Febrifuge, tonic, arthritis	1200-2100
Mallotus philippensis (Lam.) Muell. Arg.	Euphorbiaceae	Ryun	Blood purifier	Upto 1600
Mentha piperita L.	Lamiaceae	Pudina	Stomach ache	300-4000
Mentha arvensis L.	Lamiaceae	Peppermint	Vomiting, Stomach ache	1200-3300
Murraya konigii (L.) Spreng.	Rutaceae	Kari Patta	Diabetes	600-1500
Myrica esculenta Buch.- Ham. *Ex* D.Don	Myricaceae	Kafal	Constipation	1200-2000
Nerium indicum L.	Oleaceae	Kaner	Skin and Eye disorders	1200-2600
Olea glandulifera Wall.	Oleaceae	Jaitun	Fever, hair tonic	1100-2000
Origanum vulgare L.	Lamiaceae	Van tulsi	Mental disorder, Diarrhoea	2600-3300
Paeonia emodi Wallich *ex* Royle	Paeoniaceae	Chandrachun	Antidiabetic, Blood purifier	2000-3000
Paris polyphylla Sm.	Liliaceae	Satwa	Antipyretic, antispasmodic, antitussive	1800-3300
Phyllanthus emblica L.	Phyllanthaceae	Aamla	Scurvy, Jaundice	600-2600
Picrorhiza kurrooa Royle *ex* Benth.	Scrophulariaceae	Kutki	Chronic fever, Stomach ache	3300-4800
Pistacia chinensis Bung	Anacardiaceae	Karkat	Skin diseases, Fever	600-1200
Pittosporum eriocarpum Royle	Pittosporaceae	Raduthiya	Chronic bronchitis, antidote to snake poison	900-2000
Plantago ovata L.	Plantaginaceae	Isabgol	Digestive disorder, Dysentery	1200-2600
Podophyllum hexandrum Royle	Podophyllaceae	Van Kakari	Anticancer	2800-4200
Polygonatum cirrhifolum (Wallich) Royle	Liliaceae	Maha meda	Carminative, tonic	1800-3300
Polygonatum verticillatum (L.) Allioni	Liliaceae	Meda	General debility	1500-3500
Polygonum capitatum Buch.-Ham. Ex D. Don	Polygonaceae	Kafalya	Insecticide, Cut and Wounds	1500-3500
Potentilla fulgens Wallich *ex* Hook.	Rosaceae	Bajradanti	Toothache	1600-4800
Prunus cerasoides D. Don	Rosaceae	Padam, Paya	Edema	600-2600
Ranunculus laetus Wallich *ex* Hook.	Ranunculaceae	Ranunculus	Cuts and Wounds	1500-1800
Rheum emodi L.	Polygonaceae	Dolu	Abdominal pain, appetite, asthma, ulcer	3000-4200
Rhododendron arboreum Smith.	Ericaceae	Buransh	Heart problem	1300-3200
Roscoea procera Royle	Zingiberaceae	Kakoli	General debility	2000-3500
Rosemarinus officinalis L.	Lamiaceae	Rosemarry	Carminative, Antioxidant	300-1800
Rubus ellipticus Smith	Rosaceae	Hisalu	Fever, colic, coughs and sore throat	1000-2600
Rubus niveus Thunb.	Rosaceae	Kala hisalu	Antitumor, wound healing	1000-2600
Salvia lanata L.	Lamiaceae	Paniya	diarrhoea, Coryza	900-2800
Sapindus mukorossi Gaertn.	Sapindaceae	Reetha	Epilepsy	900-2500
Saussurea costus (Falc.) Lipsch.	Asteraceae	Kuth	Asthma, Leprosy	3000-4000
Selinum tenuifolium Wallich *ex* DC.	Apiaceae	Bhutkesh	Mental disorder, Asthma	2800- 3300
Senecio nudicaulis Buch.-Ham. *Ex* D. Don	Asteraceae	Neelkanthi	Fever, Boils	1200-2600
Solanum indicum L.	Solanaceae	Badi kateri	Analgesic, antipyretic, anti-inflammatory	800-2500
Solanum nigrum L.	Solanaceae	Makoy	Jaundice, Dysentery, Piles	800-3000

(Continued)

TABLE 3 Continued

Name of the plant	Family	Common name	Ethno-medicinal uses	Distribution (m asl)
Solanum torvum L.	Solanaceae	Turkey berry	Sedative, diuretic and digestive	400-1600
Swertia angustifolia Buch.-Ham. *Ex* D. Don	Gentianaceae	Chirayata	Fever, Asthma	600-2600
Tagetus minuta L.	Asteraceae	Van Hajara	Earache	800-2600
Taxus wallichiana L.	Taxaceae	Thuner	Cancer, Ulcer	2400-3000
Terminalia bellirica (Gaertn.) Roxb.	Combretaceae	Harad	Cough, Triphala preparation	500-1200
Terminalia chebula Retz.	Combretaceae	Baheda	Cough, Triphala preparation	500-1200
Thalictrum foliolosum DC.	Ranunculaceae	Mamira	Fever	1800-3500
Trillium govanianum Wall ex D.Don	Liliaceae	Nag chatri	Antiseptic, antispasmodic, diuretic	2700-4000
Tsuga dumosa (D.Don) Eichler	Pinaceae	Tansen	Bleeding wounds	1700- 3500
Urtica dioica L.	Urticaceae	Nettle	Gout, urinary diseases	Upto 3500
Valeriana jatamansi DC.	Valerianaceae	Samyo	Mental disorders, Insecticide	1500-3300
Verbascum thapsus L.	Scrophulariaceae	Ekalveer	Cataract	1000-4000
Viburnum cotinifolium D.Don	Caprifoliaceae	Dhinu	Digestive disorder	1800-3200
Viola canescens Wall.	Violaceae	Vanfasa	Coryza, Malarial fever, Asthma	1400-2600
Vitex negundo L.	Verbenaceae	Nirgundi	Jaundice	500-2600
Withania somnifera (L) Dunal	Solanaceae	Aswagandha	Arthritis, anxiety, and insomnia	300-2700
Zanthoxylum armatum DC.	Rutaceae	Timur	Pyorrhoea	1200-2400

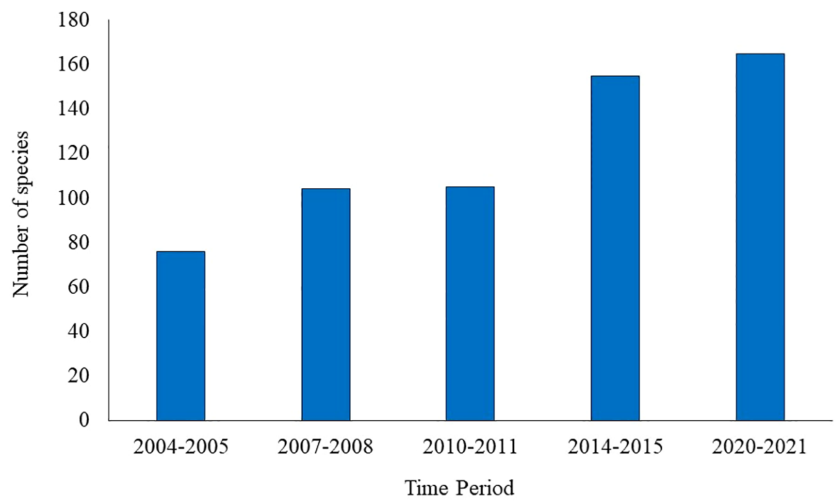

FIGURE 4
Comparative status of species richness of birds over the years in the Restoration Model.

other species. It is reported that the presence of seed sources in the restoration site ensures the availability of propagules for seedling production (Budiharta et al., 2014; Uriarte and Chazdon, 2016; César et al., 2021). Simple engineering techniques and interventions adopted during the initial stage of implementation ensured soil stabilisation, prevented soil erosion, reduced runoff, and improved percolation of water at the restoration site, as also reported in previous studies (Schultz et al., 2012; Negi et al., 2015; Kremen and Merenlender, 2018).

Naturalisation of various plant species in the restoration site, especially wild edible plants, has provided the base for various fruit-eating and nectar-feeding birds and butterflies throughout the year; this further ensured the diversity of other faunal species, such as insects. The change in species richness of butterflies reflects improvement in

TABLE 4 Threatened birds seen at 'Surya Kunj', GBPNIHE, Almora.

Species	Season	Population	IBA Criteria	IUCN Category*
Red-headed Vulture (*Sarcogyps calvus*)	Resident	Present	A1	Critically Endangered
White-rumped Vulture (*Gyps benghalensis*)	Resident	Present	A1	Critically Endangered
Steppe Eagle (*Aquila nipalensis*)	Winter	Present	A1	Endangered
Egyptian Vulture (*Neophron perinopterus)*	Summer	Present	A1	Endangered

*Source: The IUCN Red List of Threatened Species. Version 2016-2. <www.iucnredlist.org>.

habitat conditions. Birds are one among many forest-associated species that are facing the threat of habitat degradation; however, the population of birds increased in our restoration site. The Important Bird Area (IBA) programme of BirdLife International is a worldwide initiative to identify and protect the world's birds (BirdLife International, 2021). Considering the four criteria used for designating a site for conservation, Criteria A1, in general, states that the regular presence of a Critically Endangered (CE) or Endangered (E) species, irrespective of population size, qualifies a site as an IBA (BirdLife International, 2016). Therefore, 'Surya-Kunj with the regular presence of four threatened bird species, qualifies as an IBA under criteria A1. Further, 'Surya-Kunj' harbours avifaunal diversity that is comparable to the nearest IBA site (Binsar Wildlife Sanctuary; 166 spp.). Conservation of MP diversity in the 'Surya-Kunj' (i) provides base material for in-depth research on the phytochemical and genetic attributes of these MPs, (ii) develops reproducible propagation protocols using conventional and *in vitro* methods, (iii) cater to the need of locals by making available the elite planting material, and (iv) impart knowledge and build capacity of diverse stakeholder on conservation and sustainable utilisation of MPs. The richness of MPs initially increased from 20 in 1995 to over 90 plants in 2024, including RET species. In this way, the restoration site contributes to the *ex-situ* conservation of important RET species and is used as a genetic repository of MPs for mass multiplication. Reproducible propagation protocols have helped develop quality planting material to promote the cultivation and recovery/reintroduction of the selected species in their natural habitats.

Biodiversity conservation is widely practiced through the generation of awareness among diverse stakeholders. Considering the importance of education in conservation-related issues through non-formal means, various conservation education programmes have been organised in the present study, as done in the past by the Institute (Dhar et al., 2002). The conservation programme aimed to sensitise the young minds towards valuing biodiversity and its conservation, providing restoration as an example. The literature indicates that investments in restoration or FLR require good governance, a reliable policy environment, and reliable mechanisms to resolve stakeholder conflicts (Sabogal et al., 2015). IUCN and WRI created a Restoration Opportunities Assessment Methodology (ROAM) to help stakeholders what restoration activities provide the greatest ecological, social, and economic benefits in a particular area of degraded land (Hanson et al., 2015). Equitable climate mitigation and biodiversity conservation from forest restoration require the inclusion and participation of local communities (Brancalion et al., 2017; Loft et al., 2017; Pathak et al., 2021). Findings reveal that empowering the local community in restoration projects through technical training and equitable resource access reduces risks associated with community resource management. Our study demonstrated that restoration with community participation ensures biodiversity conservation, a steady flow of ecosystem goods, and a sense of awareness.

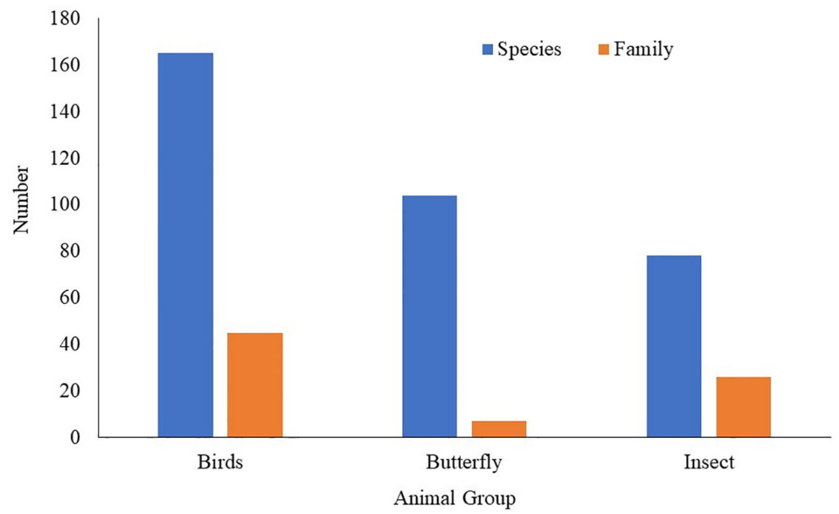

FIGURE 5
Richness of birds, butterflies and insects in the Restoration Model.

5 Conclusion

The three-decade-long restoration of the 'Surya-Kunj' site in the western Himalaya demonstrates that degraded landscapes can be successfully transformed into a self-sustaining, biodiversity-rich restoration model through a combination of scientific planning, community participation, and long-term commitment. The present study has demonstrated that the ecological restoration model has ample potential for biodiversity conservation, livelihood enhancement, and ecosystem-based services. The restored habitat now supports rich plant and faunal diversity, including medicinal plants, lichens, bryophytes, birds, butterflies, and insects, reflecting improved ecosystem complexity and resilience. Native Himalayan species showed better survival and regeneration than non-native species, underscoring the importance of prioritising local flora in restoration programs. Community involvement ensured protection and sustainable use of resources and facilitated replication of restoration practices in surrounding areas. Integrating conservation education further strengthened local stewardship and inspired broader environmental awareness. The 'Surya-Kunj' model offers a replicable and adaptable framework for ecological restoration in Himalayan and other mountain landscapes, contributing to biodiversity conservation, ecosystem service recovery, and sustainable livelihoods. Such successful ecological restoration projects are relevant to national and global environmental obligations like REDD+, CBD, and NDCs.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding authors.

Author contributions

VN: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. RP: Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. BD: Validation, Writing – review & editing. SP: Funding acquisition, Writing – review & editing. RJ: Writing – review & editing. SA: Formal Analysis, Validation, Writing – review & editing. KS: Writing – review & editing. IB: Conceptualization, Supervision, Writing – review & editing. SS: Writing – review & editing.

Funding

The author(s) declare financial support was received for the research and/or publication of this article. Ministry of Environment, Forest and Climate Change (MoEF& CC), Government of India, for financial support under the Lead Botanical Garden.

Acknowledgments

The authors thank the Director, G.B. Pant National Institute of Himalayan Environment (NIHE), Kosi-Katarmal, Almora, for the facilities. All the authors are highly thankful to Late Dr. U. Dhar and Late Dr. R.S. Rawal (Former Directors, GBPNIHE) for setting up and conceptualising the idea of the restoration model at GBPNIHE and implementing it throughout the Himalayan region. Partial funding from the Ministry of Environment, Forest and Climate Change (MoEF&CC) under the LEAD BG project is gratefully acknowledged. We also acknowledge all the Scientists, Students, and other employees of the GBPNIHE who directly and indirectly contributed to the development of the successful restoration model- 'Suryakunj'.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2025.1663322/full#supplementary-material

References

Adams, W. M., Aveling, R., Brockington, D., Dickson, B., Elliott, J., Hutton, J., et al. (2004). Biodiversity conservation and the eradication of poverty. *Science* 306, 1146–1149. doi: 10.1126/science.1097920

Alexander, S., Aronson, J., Whaley, O., and Lamb, D. (2016). The relationship between ecological restoration and the ecosystem services concept. *Ecol. Soc.* 21. doi: 10.5751/ES-08288-210134

Ali, H., Rafiq, M., and Shang, Z. (2024). "Ecological conservation and restoration in the Indian Himalaya Region," in *Sustainable Ecological Restoration and Conservation in the Hindu Kush Himalayan Region: A Comprehensive Review* (CABI), 117–135. GB.

Anjum, N., Ridwan, Q., Sharma, M., Hanief, M., Pant, S., Wani, Z. A., et al. (2023). "Changing climatic scenarios: impacts, vulnerabilities, and perception with special reference to the Indian Himalayan region," in *Climate Change in the Himalayas* (Academic Press), 201–215.

Aronson, J., and Alexander, S. (2013). Ecosystem restoration is now a global priority: time to roll up our sleeves. *Restor. Ecol.* 21, 293–296. doi: 10.1111/rec.12011

Ashraf, A., and Ahmad, I. (2024). Evaluation of soil loss severity and ecological restoration approach for sustainable agriculture in the Hindu Kush, Karakoram and Himalaya region. *J. Mountain Sci.* 21, 1509–1521. doi: 10.1007/s11629-023-8385-y

Bai, Z. G., Dent, D. L., Olsson, L., and Schaepman, M. E. (2008). Proxy global assessment of land degradation. *Soil Use Manage.* 24, 223–234. doi: 10.1111/j.1475-2743.2008.00169.x

Bastin, J. F., Finegold, Y., Garcia, C., Mollicone, D., Rezende, M., Routh, D., et al. (2019). The global tree restoration potential. *Science* 365, 76–79. doi: 10.1126/science.aax0848

Bhandari, M., Arya, R., Tewari, S. D., Joshi, P., Pathak, R., Negi, G. C. S., et al. (2019). *Bryophyte Diversity in Surya-Kunj (Contribution to Nature Interpretation and Learning-IV)* (Kosi- Katarmal, Almora, Uttarakhand, INDIA: GBPNIHESD).

Bhatt, D., Chandra Sekar, K., Rawal, R. S., Nandi, S. K., and Dhyani, P. P. (2016). *Tree diversity of Western Himalaya* (Almora, Uttarakhand, India: GB Pant Institute of Himalayan Environment & Development), 52.

Bhatt, I. D., Negi, V. S., and Rawal, R. S. (2020). "Promoting Nature-Based Solution (NbS) through restoration of degraded landscapes in the Indian Himalayan Region," in *Nature-based Solutions for Resilient Ecosystems and Societies* (Springer, Singapore), 197–211.

Bhattacharjee, A. (2020). "Forest landscape restoration as a nbS strategy for achieving bonn challenge pledge: lessons from India's restoration efforts," in *Nature-based Solutions for Resilient Ecosystems and Societies* (Springer, Singapore), 133–147.

Bhattacharya, A., Rawal, R. S., Negi, G. C. S., Joshi, R., Sharma, S., Rawat, D. S., et al. (2018). *Assessing Landscape Restoration Opportunities for Uttarakhand* (India, New Delhi: IUCN-India).

BirdLife International (2016). *Global IBA Criteria. Important Bird and Biodiversity Areas (IBAs)* (Cambridge, United Kingdom: BirdLife International). Available online at: http://datazone.birdlife.org/site/ibacritglob.

BirdLife International (2021). *About BirdLife International* (Cambridge, United Kingdom: BirdLife International). Available online at: https://www.birdlife.org/worldwide/partnership/about-birdlife.

Bonn Challenge (2019). *Forest Landscape Restoration and the Bonn Challenge in Eastern and South-East Europe* (UNECE). Available online at: https://unece.org/fileadmin/DAM/timber/meetings/2019/20191216/FLR-backgrounder2019.pdf. Background paper (Accessed January 28, 2025).

Brancalion, P. H., and Chazdon, R. L. (2017). Beyond hectares: four principles to guide reforestation in the context of tropical forest and landscape restoration. *Restor. Ecol.* 25, 491–496. doi: 10.1111/rec.12519

Brancalion, P. H., Lamb, D., Ceccon, E., Boucher, D., Herbohn, J., Strassburg, B., et al. (2017). Using markets to leverage investment in forest and landscape restoration in the tropics. *For. Policy Economics* 85, 103–113. doi: 10.1016/j.forpol.2017.08.009

Brooks, J. S., Waylen, K. A., and Borgerhoff Mulder, M. (2012). How national context, project design, and local community characteristics influence success in community-based conservation projects. *Proc. Natl. Acad. Sci.* 109, 21265–21270. doi: 10.1073/pnas.1207141110

Brudvig, L. A. (2011). The restoration of biodiversity: where has research been and where does it need to go? *Am. J. Bot.* 98, 549–558. doi: 10.3732/ajb.1000285

Budiharta, S., Meijaard, E., Erskine, P. D., Rondinini, C., Pacifici, M., and Wilson, K. A. (2014). Restoring degraded tropical forests for carbon and biodiversity. *Environ. Res. Lett.* 9, 114020. doi: 10.1088/1748-9326/9/11/114020

César, R. G., Belei, L., Badari, C. G., Viani, R. A., Gutierrez, V., Chazdon, R. L., et al. (2021). Forest and landscape restoration: A review emphasizing principles, concepts, and practices. *Land* 10, 28. doi: 10.3390/land10010028

Chakraborty, A., Joshi, P. K., and Sachdeva, K. (2018). Capturing forest dependency in the central Himalayan region: Variations between Oak (Quercus spp.) and Pine (Pinus spp.) dominated forest landscapes. *Ambio* 47, 504–522. doi: 10.1007/s13280-017-0947-1

Chazdon, R., and Brancalion, P. (2019). Restoring forests as a means to many ends. *Science* 365, 24–25. doi: 10.1126/science.aax9539

Chettri, N., and Sharma, E. (2016). Reconciling the mountain biodiversity conservation and human wellbeing: drivers of biodiversity loss and new approaches in the Hindu-Kush Himalayas. *Proc. Indian Natl. Sci. Acad.* 82, 53–73. doi: 10.16943/ptinsa/2016/v82i1/48378

Dhar, U., Rawal, R. S., Airi, S., Bhatt, I. D., and Samant, S. S. (2002). Promoting outreach through conservation education programmes–Case study from Indian Himalayan Region. *Curr. Sci.* 82, 808–815. doi: 10.1016/j.cosust.2014.11.002

Díaz, S., Demissew, S., Carabias, J., Joly, C., Lonsdale, M., Ash, N., et al. (2015). The IPBES Conceptual Framework—connecting nature and people. *Curr. Opin. Environ. sustainability* 14, 1–16. doi: 10.1016/j.cosust.2014.11.002

Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Guèze, M., Agard, J., et al. (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. *Intergovernmental Science-Policy Platform Biodiversity Ecosystem Services.*

Erbaugh, J. T., Pradhan, N., Adams, J., Oldekop, J. A., Agrawal, A., Brockington, D., et al. (2020). Global forest restoration and the importance of prioritizing local communities. *Nat. Ecol. Evol.* 4, 1472–1476. doi: 10.1038/s41559-020-01282-2

Gebrehiwot, K., and Hundera, K. (2014). Species composition, plant community structure and natural regeneration status of Belete moist evergreen montane forest, Oromia regional state, Southwestern Ethiopia. *Momona Ethiopian J. Sci.* 6, 97–101. doi: 10.4314/mejs.v6i1.102417

Guo, Y., Wu, L. Z., Yao, Y., Qin, F., and Qi, W. (2013). Carbon stocks and carbon sequestration potentials in ecosystems of two afforestation species in low hills of northern Yanshan Mountains. *J. Food Agric. Environ.* 11, 2383–2388.

Hanson, C., Buckingham, K., Dewitt, S., and Laestadius, L. (2015). *Restoration diagnostic* (Washington D.C., USA: World Resources Institute).

Höhl, M., Ahimbisibwe, V., Stanturf, J. A., Elsasser, P., Kleine, M., and Bolte, A. (2020). Forest landscape restoration—what generates failure and success? *Forests* 11, 938. doi: 10.3390/f11090938

IUCN (2014). *Assessing forest landscape restoration opportunities nationally: A guide to the Restoration Opportunities Assessment Methodology (ROAM)* (Gland, Switzerland: IUCN). Working Paper (Road-test edition).

IUCN (2021). *Forests and climate change*. Available online at: https://www.iucn.org/resources/issues-briefs/forests-and-climate-change (Accessed February 23, 2025).

Iype, A. H., Suryawanshi, K., and Khanyari, M. (2025). Restoration in the Western Himalaya: a systematic review of current efforts and implications for the future. *Restor. Ecol.* 33, e14378. doi: 10.1111/rec.14378

Jinger, D., Kaushal, R., Kumar, R., Paramesh, V., Verma, A., Shukla, M., et al. (2023). Degraded land rehabilitation through agroforestry in India: Achievements, current understanding, and future prospectives. *Front. Ecol. Evol.* 11, 1088796. doi: 10.3389/fevo.2023.1088796

Joshi, Y., Bhakuni, G., Bisht, D., Tripathi, M., Bisht, K., Upadhyay, S., et al. (2014). Lichen colonization on nylon net houses in Surya-Kunj Nature Interpretation site, Kosi-Katarmal, Almora, Uttarakhand. *Curr. Sci.* 106, 673–675.

Joshi, R. K., Kapkoti, B., Rawal, R. S., Bhatt, I. D., and Dhyani, P. P. (2016b). *Diversity of Butterflies in Surya-Kunj (Contribution to Nature Interpretation and Learning)* (Kosi-Katarmal, Almora, Uttarakhand, INDIA: GBPIHED).

Joshi, K. K., and Negi, G. C. S. (2005). Addition to the avifauna of GBPIHED campus. *Hima Paryavaran* 17, 11–12.

Joshi, R. K., Pathak, R., Kapkoti, B., Rawal, R. S., Bhatt, I. D., and Dhyani, P. P. (2016a). *Diversity of Birds in Surya-Kunj (Contribution to Nature Interpretation and Learning-II)* (Kosi-Katarmal, Almora, Uttarakhand, INDIA: GBPIHED).

Kothari, K., Negi, G. C. S., and Choudhury, D. (2004). Survey of avifauna of GBPIHED campus, Kosi-Katarmal, Almora. *Hima Paryavaran* 16, 9–13.

Kremen, C., and Merenlender, A. M. (2018). Landscapes that work for biodiversity and people. *Science* 362. doi: 10.1126/science.aau6020

Loft, L., Pham, T. T., Wong, G. Y., Brockhaus, M., Le, D. N., Tjajadi, J. S., et al. (2017). Risks to REDD+: potential pitfalls for policy design and implementation. *Environ. Conserv.* 44, 44–55. doi: 10.1017/S0376892916000412

Lu, Y., Ranjitkar, S., Harrison, R. D., Xu, J., Ou, X., Ma, X., et al. (2017). Selection of native tree species for subtropical forest restoration in southwest China. *PloS One* 12, e0170418. doi: 10.1371/journal.pone.0170418

MacDicken, K. G. (2015). Global forest resources assessment 2015: what, why and how? *For. Ecol. Manage.* 352, 3–8. doi: 10.1016/j.foreco.2015.02.006

Maikhuri, R. K., Semwal, R. L., Rao, K. S., and Saxena, K. G. (1997). Agroforestry for rehabilitation of degraded community lands: a case study in the Garhwal Himalaya, India. *Int. Tree Crops J.* 9, 91–101. doi: 10.1080/01435698.1997.9752964

Maikhuri, R. K., Semwal, R. L., Rao, K. S., Singh, K., and Saxena, K. G. (2000). Growth and ecological impacts of traditional agroforestry tree species in Central Himalaya, India. *Agrofor. Syst.* 48, 257–272. doi: 10.1023/A:1006344812127

Maniatis, D., Scriven, J., Jonckheere, I., Laughlin, J., and Todd, K. (2019). Toward redd+ implementation. *Annu. Rev. Environ. Resour.* 44, 373–398. doi: 10.1146/annurev-environ-102016-060839

Meli, P., Rey Benayas, J. M., Balvanera, P., and Martínez Ramos, M. (2014). Restoration enhances wetland biodiversity and ecosystem service supply, but results are context-dependent: a meta-analysis. *PloS One* 9, e93507. doi: 10.1371/journal.pone.0093507

MoEF&CC (2018). *National REDD+ Strategy India* (New Delhi: Ministry of Environment, Forest and Climate Change, Government of India).

Negi, V. S., Bhatt, I. D., Phondani, P. C., and Kothyari, B. P. (2015). Rehabilitation of degraded community land in Western Himalaya: linking environmental conservation with livelihood. *Curr. Sci.* 109 (3), 520–528.

Negi, V. S., Giri, L., and Sekar, K. C. (2018b). Floristic diversity, community composition and structure in Nanda Devi National Park after prohibition of human activities, Western Himalaya, India. *Curr. Sci.* 115, 1056–1064. doi: 10.18520/cs/v115/i6/1056-1064

Negi, V. S., Joshi, B. C., Pathak, R., Rawal, R. S., and Sekar, K. C. (2018a). Assessment of fuelwood diversity and consumption patterns in cold desert part of Indian Himalaya: implication for conservation and quality of life. *J. Cleaner Production* 196, 23–31. doi: 10.1016/j.jclepro.2018.05.237

Negi, V. S., Pandey, A., Singh, A., Bahukhandi, A., Pharswan, D. S., Gaira, K. S., et al. (2024). Elevation gradients alter vegetation attributes in mountain ecosystems of eastern Himalaya, India. *Front. Forests Global Change* 7, 1381488. doi: 10.3389/ffgc.2024.1381488

Negi, V. S., Pathak, R., Dhyani, V., Durgapal, M., Joshi, R. K., and Bhatt, I. D. (2022). Land restoration in the Himalayan Region: Steps towards biosphere integrity. *Land Use Policy* 121, 106317. doi: 10.1016/j.landusepol.2022.106317

Negi, V. S., Pathak, R., Rawal, R. S., Bhatt, I. D., and Sharma, S. (2019). Long-term ecological monitoring on forest ecosystems in Indian Himalayan Region: criteria and indicator approach. *Ecol. Indic.* 102, 374–381. doi: 10.1016/j.ecolind.2019.02.035

Negi, V. S., Thakur, S., Pathak, R., Sekar, K. C., Purohit, V. K., and Wani, Z. A. (2025). Treeline structure and regeneration pattern in protected and non-protected areas, Indian western Himalaya. *Trees, Forests and People* 19, 100783.

Osuri, A. M., Kasinathan, S., Siddhartha, M. K., Mudappa, D., and Raman, T. R. S. (2019). Effects of restoration on tree communities and carbon storage in rainforest fragments of the Western Ghats, India. *Ecosphere* 10, e02860. doi: 10.1002/ecs2.2860

Palita, S. K., Ponkshe, A. V., and Dhar, U. (2011). Habitat enrichment and its impact on avian diversity: a study at GBPIHED, Kosi-Katarmal, Uttarakhand, India. *Curr. Sci.* 100 (11), 1681–1689.

Pandit, M. K., Sodhi, N. S., Koh, L. P., Bhaskar, A., and Brook, B. W. (2007). Unreported yet massive deforestation driving loss of endemic biodiversity in Indian Himalaya. *Biodiversity Conserv.* 16, 153–163. doi: 10.1007/s10531-006-9038-5

Pathak, R., Thakur, S., Negi, V. S., Rawal, R. S., Bahukhandi, A., Durgapal, K., et al. (2021). Ecological condition and management status of Community Forests in Indian western Himalaya. *Land Use Policy* 109, 105636. doi: 10.1016/j.landusepol.2021.105636

Rawal, R. S., Bhatt, I. D., Sekar, K. C., and Nandi, S. K. (2013). *The Himalayan Biodiversity: Richness, Representativeness, Uniqueness and Life-Support Values* (Kosi-Katarmal, Almora, Uttarakhand, India: GB Pant Institute of Himalayan Environment and Development (GBPIHED), 84.

Rawal, R., Negi, V. S., and Bhatt, I. D. (2021). Changing outlook on harnessing biodiversity values–A special focus on Indian Himalaya. *J. Graphic Era Univ.*, 55–82. doi: 10.13052/jgeu0975-1416.914

Rawal, R., Negi, V. S., and Tewari, L. M. (2023). Forest dynamics along altitudinal gradient covering treeline ecotone of Indian Western Himalaya. *Biologia* 78, 3339–3352. doi: 10.1007/s11756-023-01530-3

Rawal, R. S., Rawal, R., Rawat, B., Negi, V. S., and Pathak, R. (2018). Plant species diversity and rarity patterns along altitude range covering treeline ecotone in Uttarakhand: conservation implications. *Trop. Ecol.* 59, 225–239.

Rawat, B., Negi, V. S., Mishra Rawat, J., Tewari, L. M., and Rawat, L. (2013). The potential contribution of wildlife sanctuary to forest conservation: a case study from Binsar Wildlife Sanctuary. *J. Mountain Sci.* 10, 854–865. doi: 10.1007/s11629-013-2514-y

Sabogal, C., Besacier, C., and McGuire, D. (2015). Forest and landscape restoration: Concepts, approaches and challenges for implementation. *Unasylva* 66, 3.

Saxena, A. K., and Singh, J. S. (1982). A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. *Vegetatio* 50, 3–22. doi: 10.1007/BF00120674

Schultz, C. A., Jedd, T., and Beam, R. D. (2012). The Collaborative Forest Landscape Restoration Program: a history and overview of the first projects. *J. Forestry* 110, 381–391. doi: 10.5849/jof.11-082

Soh, M. C., Mitchell, N. J., Ridley, A. R., Butler, C. W., Puan, C. L., and Peh, K. S. H. (2019). Impacts of habitat degradation on tropical montane biodiversity and ecosystem services: a systematic map for identifying future research priorities. *Front. Forests Global Change* 2, 83. doi: 10.3389/ffgc.2019.00083

Thomas, E., Jalonen, R., Loo, J., Boshier, D., Gallo, L., Cavers, S., et al. (2014). Genetic considerations in ecosystem restoration using native tree species. *For. Ecol. Manage.* 333, 66–75. doi: 10.1016/j.foreco.2014.07.015

UNCCD (2019). *The New Delhi Declaration: Investing in Land and Unlocking Opportunities* (UNCCD). Available online at: https://www.unccd.int/news-events/new-delhi-declaration-investing-land-and-unlocking-opportunities.

Uriarte, M., and Chazdon, R. L. (2016). Incorporating natural regeneration in forest landscape restoration in tropical regions: synthesis and key research gaps. *Biotropica* 48, 915–924. doi: 10.1111/btp.12411

Wagley, M. P., and Karki, M. (2020). "Ecosystem-based integrated and participatory watershed management," in *Nature-based Solutions for Resilient Ecosystems and Societies* (Springer, Singapore), 51–68.

Wani, Z. A., Bhat, J. A., Negi, V. S., Satish, K. V., Siddiqui, S., and Pant, S. (2022). Conservation Priority Index of species, communities, and habitats for biodiversity conservation and their management planning: A case study in Gulmarg Wildlife Sanctuary, Kashmir Himalaya. *Front. Forests Global Change* 5, 995427. doi: 10.3389/ffgc.2022.995427

Wani, Z. A., and Pant, S. (2023). Tree diversity and regeneration dynamics in Gulmarg wildlife sanctuary, Kashmir Himalaya. *Acta Ecologica Sin.* 43, 375–381. doi: 10.1016/j.chnaes.2022.05.003

Wani, Z. A., Singh, L., Uniyal, S., Rana, S. K., Bhatt, I. D., and Nautiyal, S. (2025). Improving ecosystem vitality in India: overcoming barriers to meet National and International targets. *Environ. Sustainability.* 8, 1–13. doi: 10.1007/s42398-025-00339-x