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Ecosystem Restoration in the Indian Context: Strategies, Challenges and Case Studies

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Abstract: Ecosystem restoration is essential for reversing land degradation and achieving the United Nations Sustainable Development Goals, particularly SDG 15 (Life on Land). India, with over 96 million hectares of degraded land, faces ecological stress from climate change, deforestation, and biodiversity loss. This review examines global and national restoration frameworks with a focus on India's major initiatives such as the Green India Mission (GIA) and the National Action Plan on Climate Change (NAPCC). Case studies from Kerala demonstrate successful community-based interventions in forest, wetland and watershed ecosystems. Emerging scientific approaches such as biochar application and soil biotechnological recovery are also discussed. Despite these efforts, challenges remain due to fragmented policies, lack of ecological assessment tools, and insufficient monitoring. The study advocates for participatory, ecosystem-based restoration approach that blends scientific planning with traditional knowledge and social equity. Recommendations include building local capacity, developing region-specific ecological benchmarks, and strengthening policy coherence. Aligning with the goals of the UN Decade on Ecosystem Restoration, this review highlights opportunities for India to promote biodiversity, enhance climate resilience, and improve rural livelihoods through inclusive restoration strategies.

Keywords: Biodiversity conservation, Community-based restoration, Ecological restoration, Environmental governance, Nature based solutions

Healthy, stable, and biodiverse ecosystems are the foundation of well-being for both human and non-human species. They regulate essential ecological processes such as climate moderation, pest and disease control, and support basic life needs including water, food, raw materials, and space for living and recreation. However, ecosystems across the globe are being degraded at an alarming rate; in fact, humanity is not separate from nature but an integral part of it (IBPES 2019). Ecosystem degradation is driven by a combination of factors including climate change, pollution, invasive species, unsustainable food production, and large-scale land and ocean use changes. This degradation paradoxically supports economic growth, thereby placing long-term ecological security at risk. Ecosystem restoration is the process of assisting the recovery of degraded, damaged, or destroyed ecosystems to a healthier and more functional state (SER 2004). This process supports biodiversity, climate resilience, food security, and human well-being. In India, integration of restoration with traditional knowledge and community participation is gaining traction (Kumar et al., 2022).

According to the Global Footprint Network (GFN) (2021), sustaining current consumption levels would require 1.6 rarths, placing future ecological and economic systems in jeopardy. Land degradation not only undermines development goals but also increases the cost of meeting international environmental commitments. Restoration of damaged ecosystems has thus, emerged as a necessary complement to conservation strategies (Choudhary et al., 2022). Although restoration alone cannot resolve all environmental problems, but it serves as a key strategy under Sustainable Development Goal 15 (Life on Land) and offers multiple co-benefits for climate mitigation, disaster risk reduction, and sustainable livelihoods (Kumar et al., 2020).

Eco-Restoration in India: Indian Space Research Organisation (ISRO) in 2016, estimated that approximately 96.3 million hectares (Mha) or 29.32 per cent of India's total geographical area have been degraded or classified as wastelands (ISRO 2016). Most forest ecosystems in India, whether protected or not, are experiencing severe degradation due to anthropogenic pressures, biological invasions, and unsustainable logging practices (Ravindranath et al., 2012, Ghosh and Maiti 2021). India's ecological degradation is closely tied to socioeconomic marginalization. Many rural communities, particularly in ecologically fragile zones, face persistent exclusion from formal development processes. Limited access to education, healthcare, and infrastructure further compounds their vulnerability. Moreover, caste, gender, and religious discrimination continue to hinder equitable participation in restoration planning and policy decisions (Parthasarathy 2018, Bhattacharya 2020). Despite the presence of numerous policies in India that intersect with environmental governance such as Green India Mission, Compensatory Afforestation Fund Management and Planning Authority (CAMPA), Mahatma Gandhi National Rural Employment

Guarantee Act (MGNREA) and the National Action Plan on climate Change (NAPCC) the country still lacks a dedicated, coherent ecological restoration policy. Often, initiatives are reduced to shallow afforestation efforts rather than being guided by ecological science and restoration principles (Menz et al., 2013, Suding et al., 2015, Chazdon and Brancalion 2019, Holl and Brancalion 2020). For example, state monitoring reports document low survival and design gaps in CAMPA plantations (e.g., Uttarakhand state average ≈33%, division values as low as 16–26%, with use of exotics and limited soil–water conservation), and the national audit highlights systemic compliance and oversight failures (CAGI 2013, UK-CAMPA/FRI 2021).

For restoration to be effective in India, it must be embedded within a multidisciplinary and participatory framework that draws from ecological science, local knowledge, and socioeconomic development goals (Chazdon and Brancalion 2019, Pascual et al., 2023). A major opportunity lies in integrating ecological restoration objectives into existing national programs and leveraging international finance mechanisms such as the Global Environment Facility (GEF) and carbon markets (Dickson 2021, Mansourian and Stephenson 2023). Ecological restoration paves way for a cost-effective, long-term solution to India's overlapping crises of climate change, biodiversity loss, and rural poverty. United Nations Environment Programme (UNEP) (2021) reports that each dollar invested in ecosystem restoration yields up to $9 in ecosystem services, including carbon sequestration, flood regulation, and public health benefits. Restoration efforts can also reduce zoonotic disease risk by mitigating habitat fragmentation, a key driver of emerging pandemics (Díaz et al., 2019, Dobson et al., 2020, Keesing and Ostfeld 2021). Given that India accounts for 27.5 per cent of the world's degraded land, the country holds a strategic position in the global restoration agenda. With strong institutional coordination, scientific support, and inclusive governance, India can emerge as a leader in the UN Decade on Ecosystem Restoration (2021-2030).

Eco-Restoration in Kerala: Kerala, situated in the biodiversity-rich western ghats, faces complex ecological restoration challenges despite its comparatively high forest cover and progressive conservation framework. Ecological degradation in the state stems from multiple interacting drivers. These include the spread of invasive species (*Senna spectabilis*, *Prosopis juliflora, Lantana camara, Ageratina adenophora, Parthenium hysterophorus, etc*.; Anusree and Rajendran 2022, Prakash et al., 2022), hydrological disruptions due to unregulated land use changes, over-extraction of natural resources, unsustainable tourism expansion and the conversion of natural forests into monoculture plantations (Ravindranath et al., 2012, Ghosh and Maiti 2021). Moreover, state-led interventions in Kerala have occasionally prioritized aesthetic objectives over ecological functionality. For instance, tree-planting campaigns have sometimes favoured fast-growing exotics or monocultures, neglecting the importance of restoring native biodiversity and ecological processes (Suding et al., 2015, Holl 2017). These actions, though visually appealing, do not always lead to resilient or self-sustaining ecosystems.

The situation is exacerbated by socio-political marginalization. Tribal and rural communities inhabiting ecologically sensitive areas frequently lack formal access to infrastructure and policy processes. Structural barriers based on caste, gender, and class inhibit inclusive participation in environmental governance (Bhattacharya 2020). Consequently, restoration strategies often fail to engage these stakeholders meaningfully, undermining both ecological outcomes and social equity. Despite these challenges, Kerala has pioneered several successful community-based restoration initiatives that offer replicable models. One such example is the targeted removal of *Senna spectabilis* in Wayanad district, where tribal cooperatives collaborated with forest departments to control invasive spread through manual clearing and native species reintroduction. Another example is the Vembanad Lake restoration effort, coordinated by the Ashoka Trust for Research in Ecology and the Environment (ATREE), which leveraged local fisher's ecological knowledge to restore hydrological flow and enhance wetland biodiversity (ATREE, n.d). In the Attappadi hills, participatory watershed management combined with agroforestry practices has enabled landscape-level ecological recovery while improving livelihoods for tribal communities (Kumar et al., 2014, 2015).

Going forward, ecological restoration in Kerala must be anchored in scientific diagnostics such as biodiversity baselines, soil quality assessment, and hydrological profiling. Restoration strategies should move beyond tourism to adopt long-term, adaptive management plans that emphasize ecological processes. Additionally, scaling up nature-based solutions including mangrove regeneration, riparian buffer creation, and agroforestry diversification, which can help Kerala simultaneously meet its biodiversity conservation, climate adaptation, and sustainable development goals (Seddon et al., 2020). At the policy level, Kerala adopted the Eco restoration Policy (2021), a first of its kind state initiative, where Kerala has committed to phase out ~27,000 ha of exotic monoculture plantations (e.g., Eucalyptus, Acacia, Wattle), prioritise invasive-species removal, replace exotics with native species and restore wetlands, riverbanks, sacred groves, and coastal 'bio-shields' (mangroves) through participatory approaches with forest-dependent communities (KFD 2021). Kerala's State Action Plan on Climate Change (SAPCC) 2.0 (2023-2030) likewise foregrounds nature-based solutions, including ecosystem-based coastal protection such as mangrove afforestation and bio-shields, as part of climate adaptation (DECC 2022). Finally, aligning state-level efforts with international initiatives, the Bonn Challenge and the UN Decade on Ecosystem Restoration can unlock technical cooperation and climate finance, strengthening the institutional foundation for restoration success (IUCN n.d., UNEP and FAO n.d.).

Complexities of eco-restoration process: Ecological restoration is fundamentally a design and governance challenge, interventions must balance biophysical feasibility with social legitimacy across heterogeneous landscapes and a non-stationary climate (Chazdon and Brancalion 2019, Gann et al., 2019). Selecting appropriate reference models is particularly difficult in systems shaped by path dependence (past land uses leave long lasting legacies that push the site along certain recovery paths), altered disturbance regimes (pattern of fires, floods, grazing, *etc*), and novel species assemblages (new mix of species compared with the past due to invasions, extinctions, climate driven shifts *etc*.), in many cases, strict historical fidelity is neither achievable nor desirable. Because of these legacies trying to build the ecosystem exactly as it was historically is often impossible so the restoration programmes should make explicit trade-offs among the core objectives: biodiversity recovery, eco-hydrological stability, carbon storage and livelihood benefits and thereby choose between natural regeneration and assisted approaches based on the recovery potential and context (Holl and Aide 2011, Suding et al., 2015, Seddon et al., 2020). Operationally, this choice follows a degradation–intervention gradient (Fig. 1): when the state of degradation is high, projects begin with reclamation/ rehabilitation (rebuilding basic soil function and stability), sometimes *via* commercial reforestation/agroforestry as a transitional step; at moderate degradation, reforestation with native trees or Assisted Natural Regeneration (ANR) becomes feasible once barriers (e.g., grazing, fire, invasive pressure) are removed; where degradation is low, natural regeneration can deliver the highest biodiversity and ecosystem-service gains. Consistent with the figure axes, biodiversity/services increase up the staircase, while time and cost decline towards ANR and natural regeneration. Rigorous evaluation requires a clearly defined baseline, an explicit counterfactual (e.g., control plots or a Before–After, Control–Impact design), and process-based indicators (e.g., natural recruitment, soil function, hydrological connectivity) in addition to simple survival percentages (Palmer et al., 2005, Ruiz-Jaen and Aide 2005).

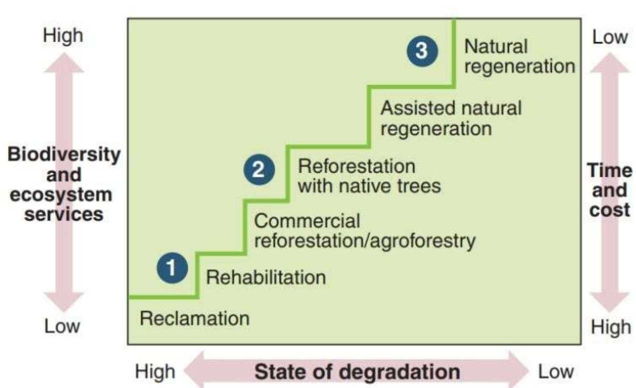

Fig. 1. Complexities of eco-restoration process (Rai 2022)

Implementation often falters because of supply-side and institutional constraints. On the supply side, ecological fit is weakened by poor provenance/seed-source matching, variable nursery quality, insufficient genetic and functional diversity in plantings, neglect of soil biota, and under-resourced after-care; moreover, the persistence of riparian, wetland, and floodplain interventions depends on hydrological management specifically, appropriate flows, groundwater regimes, and barrier operations like dams, barrages and embankments (Palmer et al., 2005, Menz et al., 2013, Gann et al., 2019). Correctly placing a site on the Fig. 1 gradient hinges on these diagnostics: misclassifying a severely degraded site as “ready for assisted natural regeneration,” or a lightly degraded site as needing heavy planting, wastes resources and depresses outcomes (Rai 2022). On the institutional side, recognized tenure, equitable benefit-sharing, and Free, Prior and Informed Consent (FPIC) enable co-design and long-term stewardship, while effective cross-agency coordination, ring-fenced maintenance finance, and performance-linked contracts (payments tied to verified outcomes) help avoid short-term, tokenistic plantings (Suding et al., 2015, Chazdon and Brancalion 2019). Finally, robust Measurement, Reporting and Verification (MRV), transparent open-data frameworks that integrate ecological and social indicators and acknowledge climate uncertainty, underpins adaptive management and facilitates access to finance (Gann et al., 2019, Seddon et al., 2020).

Various Eco-restoration initiatives in India: India has implemented a diverse array of ecological restoration strategies across its varied biogeographic regions. These initiatives span from low-intervention, passive natural recovery to scientifically intensive techniques involving biotechnology and soil engineering. Together, they illustrate the country's growing portfolio of context-specific, evidence-based approaches. One striking example of passive restoration emerged during the COVID-19 lockdown, when decreased industrial activity led to a temporary reduction in environmental stressors. The Damodar River in eastern India exhibited substantial improvements in water quality due to a sharp decline in effluent discharge. Water parameters neared the Bureau of Indian Standards (BIS 2012) norms for drinking water, as reported by Chakraborty et al. (2021). Similar patterns were observed in the Yamuna and Ganga rivers, where decreased anthropogenic pressure led to higher dissolved oxygen levels and reduced biochemical oxygen demand (Kumar et al., 2020, Varma and Jha 2023). These events underscored the latent regenerative capacity of ecosystems when disturbances are minimized.

At the other end of the spectrum are biochar-assisted soil restoration methods, which are gaining prominence for their multifaceted benefits. Biochar, a stable, carbon-rich byproduct of pyrolysis has been shown to improve soil structure, enhance microbial activity, and increase carbon sequestration. Ghosh and Maiti (2021) demonstrated that biochar produced from invasive weeds especially *Lantana camara* and *Calotropis procera* improved soil texture, pH balance, and nutrient content in degraded lands. Irfan and Mirara (2024) showed that biochar supports arbuscular mycorrhizal fungi and reduces the mobility of heavy metals in contaminated mining soils. These results highlight biochar's utility in restoring degraded soils and stabilizing toxic landscapes.

Biotechnology-integrated restoration approaches have also proven effective, particularly in post-mining landscapes. For example, Jambhulkar and Kumar (2019) successfully rehabilitated ~20 ha coal mine spoils in Maharashtra's Dhandrapur district using an integrated biotechnology approach that combined biofertilizers (e.g., *Azotobacter*, *Rhizobium*, VAM fungi) and industrial effluent treatment plant (ETP) sludge (such as organic amendments). Their results showed notable gains in vegetation biomass, canopy structure, and heavy metal immobilization. Complementing this, Juwarkar and Jambhulkar (2008) demonstrated, in a 10-ha coal-spoil field trial, that ETP sludge @ 50 t ha^{-1} along with biofertilizers markedly increased native microbial groups (previously near-absent) and immobilised heavy metals (e.g., Cr 41%, Zn 43%, Cu 37%) thereby accelerating soil functional recovery and enabling vegetation establishment. On other hand, species composition and planting strategy are also critical to the success of restoration efforts. Singh et al. (2012) found that mixed-species plantations significantly improved soil microbial diversity, enzymatic activity, and ecological stability in sodic lands compared to monocultures. More recently, Mandal et al. (2024) reported that polyculture restoration in riparian zones of Odisha led to enhanced groundwater recharge, biodiversity, and erosion control. Community-based initiatives have also demonstrated substantial success. Pattnaik (2014) documented the restoration of wetlands through the integration of local ecological knowledge and hydrological interventions. Similarly, Cao et al. (2022) applied watershed-based restoration models in semi-arid zones, which led to improvements in vegetation cover, groundwater levels, and agricultural productivity. These examples underscore the importance of participatory governance and social ownership in achieving long-term restoration goals. Collectively, these case studies illustrate that India's ecological restoration landscape is evolving toward a more diversified, science-based, and community-inclusive model. Scaling up such approaches will require capacity building, interdepartmental coordination, and policy support to embed restoration within broader environmental and developmental planning.

Tools for assessing progress of ecological restoration: Measuring the success of ecological restoration is inherently complex due to the long timescales involved and the variability of ecological responses across regions and ecosystems. Restoration does not necessarily aim to return an ecosystem to a pristine or historical state, but rather to initiate or accelerate recovery along a trajectory that increases ecological integrity, functionality, and resilience (Clewell and Aronson 2012, Gann et al., 2019). To provide structure and consistency in evaluating outcomes, the Society for Ecological Restoration (SER) introduced the *International Standards for the Practice of Ecological Restoration* (McDonald et al., 2016). Central to these standards is the Five-Star Recovery System, which assesses how closely a recovering site resembles a reference ecosystem across key ecological parameters such as species composition, structural complexity, and ecosystem functions. A score ranging from one to five stars reflects a continuum of recovery, with five stars indicating a high degree of ecological integrity.

Complementing this system is the Recovery Wheel (Fig. 2), a diagnostic and visualization tool designed to track progress across multiple attributes including biodiversity, ecosystem functionality, resilience to disturbance, and landscape connectivity (McDonald et al., 2016). This wheel enables restoration practitioners to identify underperforming components and prioritize interventions. It also supports adaptive management by allowing repeated assessments over time (McDonald et al., 2016, Gann et al., 2019). Both tools are grounded in the principle that restoration is a

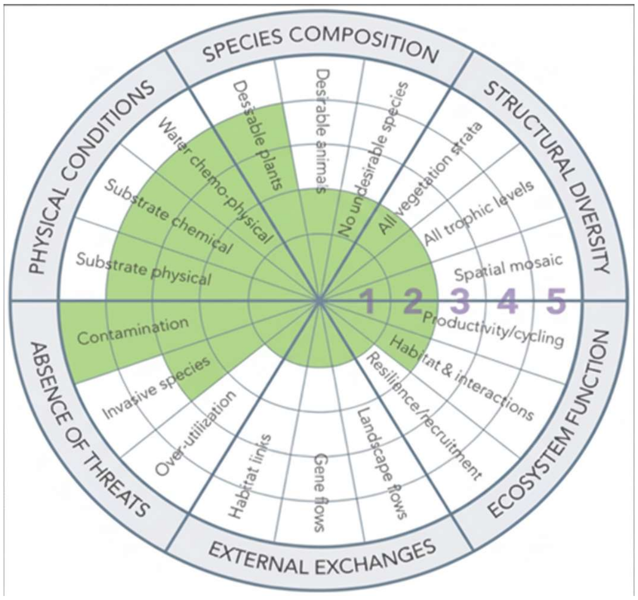

Fig. 2. Progress evaluation "recovery wheel" (McDonald et al., 2016)

dynamic and iterative process. Practitioners are encouraged to adopt a *trajectory-based approach* rather than relying on fixed endpoints, recognizing that partial or alternate forms of recovery can still yield meaningful ecological and societal benefits (Holl and Brancalion 2020). While these frameworks are increasingly used in global restoration programs, their application in India remains limited, often due to a lack of baseline data, insufficient training, or institutional fragmentation. Even so, several programmes are beginning to operationalise these frameworks in practice. In Uttarakhand, biodiversity offset projects attached to roads and hydropower, now set a "no net loss" type of target. Developers finance assisted natural regeneration and enrichment of oak-broadleaf forests on Van Panchayat and reserve forest lands. Sites are chosen using straight forward habitat condition scores alongside slopes and landslide risk maps. Monitoring revisits permanent plots, tracks seedlings through to recruitment and uses indicator fauna such as pheasants and ungulates. Independent audits check progress at agreed milestones (Tambe et al., 2022).

In the Western Ghats, Eco-development Committees (EDCs) and partner non-governmental organisations implement standardised, community-based monitoring using resource-efficient protocols. Field teams employ participatory maps and fixed photo-points, maintain mobile-based patrol records and fire-incidence logs, and conduct rapid line-transects and habitat assessments to track regeneration and invasive-species pressure. These observations are supplemented by low-cost hydrological and soil measurements including spring discharge, baseflow, and infiltration to link interventions with water-security outcomes (ATREE, n.d.). Taken together, these pilots demonstrate that standard baselines, control/counterfactual plots, and process-based indicators can be integrated into routine operations, generating evidence that is trusted by communities and verifiable by funders (Tambe et al., 2022). To scale up implementation, Indian policymakers and environmental agencies must invest in- a) Training programs for local practitioners and forest staff, b) Integration of monitoring tools into project management protocols, and c) Development of region-specific reference ecosystems based on historical data, local knowledge, and current site potential. Moreover, as per Mansourian and Stephenson (2023) the use of remote sensing, GIS-based modelling, and citizen science platforms can greatly enhance data collection and monitoring efficiency, making these frameworks more accessible and scalable.

CONCLUSION

Ecological restoration in India holds transformative potential, not only to reverse decades of environmental degradation but also to catalyse sustainable development, strengthen climate resilience, and empower marginalized communities. However, realizing this potential requires a shift from symbolic actions to scientifically grounded, context-specific, and participatory approaches. Before initiating restoration interventions, it is imperative to conduct comprehensive ecological assessments. These should evaluate site-specific degradation drivers, biodiversity baselines, soil characteristics, hydrological conditions, and socio-economic factors. Restoration strategies must be designed based on such diagnostics, adhering to internationally accepted principles like those outlined by the Society for Ecological Restoration. Multidisciplinary approaches are also essential, for instance, effective restoration should integrate actions such as invasive species control, nutrient cycling enhancement, water resource management, and livelihood support. Projects that combine ecological goals with human well-being through agroforestry, wetland restoration, or urban green infrastructure tend to be more sustainable and socially accepted. Equally critical is the establishment of robust monitoring and evaluation frameworks. The five-star recovery system and the recovery wheel provide adaptable, science-based tools to assess restoration progress over time. When tailored to local contexts, these tools can help guide adaptive management and promote transparency, accountability, and learning. Aligning restoration with national development goals and global frameworks—such as the UN Decade on Ecosystem Restoration, the Bonn Challenge, and India's NDCs under the Paris Agreement—can unlock technical and financial resources. Furthermore, integrating restoration metrics into programs like CAMPA, MGNREGA, and the GIM can institutionalize restoration within existing policy structures. Ultimately, the long-term success of ecological restoration in India will depend not only on sound science and policy alignment, but also on inclusive governance, local stewardship, and cross-sectoral collaboration. Restoration must move beyond project-based interventions to become a core principle of land management and national planning. Embracing emerging tools, participatory models, and transdisciplinary knowledge systems will ensure that restoration is not just ecologically effective but also socially equitable and resilient in the face of future challenges.

REFERENCES

Anusree ME and Rajendran A 2022. Invasive Succulents in Malabar Region of Kerala, India. *Indian Journal of Ecology* **49**(5): 1608-1612.

ATREE (Ashoka Trust for Research in Ecology and the Environment) (n.d.). *Vembanad-Community Environmental Resource Centre (CERC): Key areas of work (traditional ecological knowledge, participatory monitoring, Lake Protection Forums)*. Ashoka Trust for Research in Ecology and the Environment, Bengaluru, India. (Accessed 27 September 2025), Available at: https://www.atree.org/vembanad.

Bhattacharya H 2020. Environmental and socio-economic sustainability in India: Evidence from CO_2 emission and economic inequality relationship. *Journal of Environmental Economics and Policy* **9**(1): 57-76.

BIS (Bureau of Indian Standards) 2012. *Indian Standard: Drinking Water—Specification (IS 10500:2012)*. Bureau of Indian Standards, New Delhi. Available at: http://cgwb.gov.in/documents/wq-standards.pdf. (Accessed 27 September 2025).

Cao Z, Wang S, Luo P, Xie D and Zhu W 2022. Watershed ecohydrological processes in a changing environment: Opportunities and challenges. *Water* **14**(9): 1502.

Chakraborty B, Roy S, Bera A, Adhikary PP, Bera B, Sengupta D and Shit PK 2021. Eco-restoration of river water quality during COVID-19 lockdown in the industrial belt of Eastern India. *Environmental Science and Pollution Research* **28**: 25514-25528.

Chazdon R and Brancalion P 2019. Restoring forests as a means to many ends. *Science* **365**: 24-25.

Choudhary R, Singh R and Kumar P 2022. Land degradation and its management through eco-restoration approaches in India. *Indian Journal of Ecology* **49**(2): 441-447.

Clewell AF and Aronson J 2012. *Ecological Restoration: Principles, Values, and Structure of an Emerging Profession*. Island Press, Washington, DC, USA.

CAGI (Comptroller and Auditor General of India) 2013. *Compliance Audit on Compensatory Afforestation in India (Report No. 21 of 2013)*. Comptroller and Auditor General of India, New Delhi, India.

Díaz S, Settele J, Brondízio ES, Ngo HT, Agard J, Arneth A and Zayas CN 2019. Pervasive human-driven decline of life on earth points to the need for transformative change. *Science* **366**(6471): 3100.

Dickson B 2021. *Becoming Generation Restoration: Ecosystem Restoration for People, Nature and Climate*. United Nations Environment Programme, Nairobi, Kenya. Accessed 5 June 2024, Available at: https://www.decadeonrestoration.org.

DECC (Directorate of Environment and Climate Change) 2022. *Kerala State Action Plan on Climate Change 2.0 (2023–2030)*. Directorate of Environment and Climate Change, Government of Kerala, Thiruvananthapuram, India. Available at: https://envt.kerala.gov.in/wp-content/uploads/2022/12/Kerala-State-Action-Plan-on-Climate-Change-2.0.pdf. (Accessed 27 September 2025).

Dobson AP, Pimm SL, Hannah L, Kaufman L, Ahumada JA, Ando AW and Vale MM 2020. Ecology and economics for pandemic prevention. *Science* **369**(6502): 379–381.

Gann GD, McDonald T, Walder B, Aronson J, Nelson CR, Jonson J and Dixon KW 2019. International principles and standards for the practice of ecological restoration. *Restoration Ecology* **27**(1): 1-46.

GFN (Global Footprint Network) 2021. *Ecological Footprint*. Global Footprint Network, Oakland, California, USA. Available at: https://www.footprintnetwork.org/our-work/ecological-footprint (Accessed 27 September 2025).

Ghosh D and Maiti SK 2021. Biochar-assisted eco-restoration of coal mine degraded land to meet united nation sustainable development goals. *Land Degradation and Development* **32**(16): 4494-4508.

Holl KD and Aide TM 2011. When and Where to Actively Restore Ecosystems? *Forest Ecology and Management* **261**(10): 1558-1563.

Holl KD 2017. Restoring tropical forests from the bottom up. *Science* **355**(6324): 455-456.

Holl KD and Brancalion PH 2020. Tree planting is not a simple solution. *Science* **368**(6491): 580-581.

IBPES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) 2019. *Global Assessment Report on Biodiversity and Ecosystem Services*, p. 56. **In:** Brondizio E S, Settele J, Díaz S and Ngo HT (eds). *Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany.* Available at: https://doi.org/10.5281/zenodo.3553579 (Accessed 27 September 2025).

Irfan MF and Mirara F 2024. Biochar application in improving soil health and sustainability. *Bulletin of Biological and Allied Sciences Research* **2024**(1): 81.

ISRO (Indian Space Research Institute) 2016. *Desertification and Land Degradation Atlas 2016*. Indian Space Research Organisation, Ahmedabad. Available at: https://www.sac.gov.in/SACSITE/Desertification_Atlas_2016_SAC_ISRO.pdf (Accessed 27 September 2025).

IUCN (International Union for Conservation of Nature) n.d. *About the Bonn Challenge*. Available at: https://www.bonnchallenge.org/about (Accessed 27 September 2025).

Jambhulkar HP and Kumar MS 2019. Eco-restoration approach for mine spoil overburden dump through biotechnological route. *Environmental Monitoring and Assessment* **191**: 1-16.

Juwarkar AA and Jambhulkar HP 2008. Phytoremediation of coal mine spoil dump through integrated biotechnological approach. *Bioresource Technology* **99**(11): 4732-4741.

Keesing F and Ostfeld RS 2021. Impacts of biodiversity and biodiversity loss on zoonotic diseases. *Proceedings of the National Academy of Sciences of the United States of America* **118**(17): e2023540118.

KFD (Kerala Forest Department) 2021. *Ecorestoration Policy 2021.* Forest and Wildlife Department, Government of Kerala, Thiruvananthapuram. Available at: https://forest.kerala.gov.in/images/EcorestorationPolicy/EcorestorationPolicy_2021_English.pdf (Accessed 27 September, 2025).

Kumar D, Malik DS, Kumar N, Gupta N and Gupta V 2020. Spatial changes in water and heavy metal contamination in water and sediment of river Ganga in the river belt Haridwar to Kanpur. *Environmental Geochemistry and Health* **42**: 2059-2079.

Kumar D, Malik DS, Kumar N, Gupta N and Gupta V 2022. Biodiversity conservation and ecosystem restoration through community participation. *Indian Journal of Ecology* **49**(1): 243-248.

Kumar RS, Binu NK and Kundu S 2014. Good Governance as a Precursor for Equity, Social Capital Building and Outcome Realizations in Participatory Forest Management Strategies: A Case Analysis of the Attappady Wasteland Comprehensive Environmental Conservation Project, Kerala, India, p 45. **In:** *Community-Based Forest Management in the SAARC Region*. SAARC Forestry centre, Thimphu, Bhutan.

Kumar R, Binu NK, Caballero JJ and Kundu S 2015. Rehabilitation of degraded mountain forests with an integrated eco restoration model: A case study of the Attappady Hills, Kerala, India. *SAARC Forestry Journal* **4**: 32-45.

Kumar S, Choudhary A, Sharma V and Patra A 2020. Sustainable land management for combating land degradation and achieving land degradation neutrality. *Indian Journal of Ecology* **47**: 81-86.

Mandal KG, Banerjee K, Purbey SK and Kumar R 2024. Potential Measures to Enhance Ecosystem Services of Flood-Prone and Wetland Agricultural Systems. *Journal of Agricultural Physics* **24** (SI): 108-122.

Mansourian S and Stephenson PJ 2023. Exploring challenges and lessons for monitoring forest landscape restoration. *Current Landscape Ecology Reports* **8**(4): 159-170.

McDonald T, Gann GD, Jonson J and Dixon KW 2016. *International standards for the practice of ecological restoration—Including Principles and Key Concepts*. Society for Ecological Restoration, Washington, DC, USA.

Menz MH, Dixon KW and Hobbs RJ 2013. Hurdles and opportunities for landscape-scale restoration. *Science* 339(6119): 526-527.

Palmer MA, Bernhardt ES, Allan JD, Lake PS, Alexander G, Brooks S and Sudduth E 2005. Standards for ecologically successful river restoration. *Journal of Applied Ecology* **42**(2): 208-217.

Parthasarathy D 2018. Inequality, uncertainty, and vulnerability: Rethinking governance from a disaster justice perspective. *Environment and Planning E: Nature and Space* **1**(3): 422-442.

Pascual U, Balvanera P and Christie M 2023. Editorial overview: Leveraging the multiple values of nature for transformative change to just and sustainable futures-insights from the IPBES values assessment. *Current Opinion in Environmental Sustainability* **64**: 101359.

Pattnaik AK 2014. Hydrological intervention for restoration of a coastal ecosystem; lesson learnt From Chilika Lake, India. *Wetland Research* **4**: 27-32.

Prakash L, Manikandan P and Muthumperumal C 2022. Documentation of invasive Alien plant species in Anaikatty Hills, Coimbatore, Western Ghats. *Indian Journal of Ecology* **49**(3): 698-702

Rai PK 2022. Environmental degradation by invasive alien plants in the Anthropocene: Challenges and prospects for sustainable restoration. *Anthropocene Science* **1**(1): 5-28.

Ravindranath NH, Srivastava N, Murthy IK, Malaviya S, Munsi M and Sharma N 2012. Deforestation and forest degradation in India-implications for REDD+. *Current Science* **102**(8): 1117-1125.

Ruiz-Jaen MC and Aide TM 2005. Restoration success: How is it Being Measured? *Restoration Ecology* **13**(3): 569-577.

Seddon N, Chausson A, Berry P, Girardin CA, Smith A and Turner B 2020. Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B* **375**(1794): 20190120.

SER (Society of Ecosystem Restoration) 2004. *International Primer on Ecological Restoration*. Available at: https://www.ser-rrc.org/resource/the-ser-international-primer-on/ (Accessed 27 September 2025).

Singh K, Singh B and Singh R 2012. Changes in physico-chemical, microbial and enzymatic activities during restoration of degraded sodic land: Ecological Suitability of mixed forest over monoculture plantation. *Catena* **96**: 57-67.

Suding K, Higgs E, Palmer M, Callicott JB, Anderson CB, Baker M and Schwartz KZ 2015. Committing to ecological restoration. *Science* **348**(6235): 638-640.

Tambe S, Rawat GS, Krishen P, Ranjitsinh MK, Ghosh N, Rawat AS and Takpa J 2022. Compensatory afforestation policy in India: An analysis using an eco-restoration lens. *International Forestry Review* **24**(4): 607-618.

UK-CAMPA/FRI (Uttarakhand Compensatory Afforestation Fund Management and Planning Authority/ Forest Research Institute) 2021. *Monitoring and Evaluation of Plantation Raised under CAMPA in the State of Uttarakhand*. Forest Research Institute and CAMPA, Dehradun, India.

UNEP [United Nations Environment Programme] 2021. *Making Peace with Nature: A Scientific Blueprint to Tackle the Climate, Biodiversity and Pollution Emergencies*. United Nations Environment Programme. Available at: https://www.unep.org/resources/making-peace-nature (Accessed 27 September 2025).

UNEP and FAO. (n.d.). About the UN Decade on Ecosystem Restoration. https://www.decadeonrestoration.org/about-un-decade.

Varma K and Jha PK 2023. Spatial and seasonal variations in nutrient load and trophic status of Ganga and Yamuna Rivers in Uttar Pradesh, India. *Water Supply* **23**(6): 2553-2574.

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