



G.B. Pant Memorial Lecture - 2026

Memorial Lecture: XXXII



Prof. S. K. Barik

September 10, 2026
at Kosi-Katarmal, Almora

G.B. Pant National Institute of Himalayan Environment

(An Autonomous Institute of Ministry of Environment, Forest and Climate Change, Govt. of India)

Kosi-Katarmal, Almora, 263 643, Uttarakhand, India



Prof. S. K. Barik

Prof. Saroj Kanta Barik, *FNA, FASc, FLS, FNAAS, FNASc*, is a distinguished Indian botanist, ecologist, and scientific administrator specializing in plant ecology, biodiversity conservation, ecological restoration, ecosystem functioning, climate change, and sustainable management of bioresources. He is currently Vice-Chancellor, Professor of Botany and Dean, School of Life Sciences, North-Eastern Hill University (NEHU), Shillong. He previously served as Director, CSIR–National Botanical Research Institute (CSIR-NBRI), Lucknow (2016–2022) and concurrently as Director, CSIR–Indian Institute of Toxicology Research (CSIR-IITR), Lucknow (2020–2022). During his tenure, he also served as Theme Director of the CSIR Agriculture–Nutrition–Biotechnology Programme.

Prof. Barik began his scientific career at the State Forest Research Institute, Government of Arunachal Pradesh, before joining NEHU in 1997. He became Professor of Botany in 2006 and served as Head of the Department of Botany prior to assuming leadership of CSIR-NBRI. His research encompasses biodiversity conservation, ecosystem ecology, restoration, taxonomy, and climate change, with significant contributions to the discovery of several new plant species from the Himalaya and North-East India and developed six plant-based healthcare products.

Prof. Barik has authored numerous research papers in high-impact peer-reviewed journals, books, and book chapters, and has guided several Ph.D. scholars. He has served on the Governing Bodies of the G.B. Pant National Institute of Himalayan Environment and the National Institute of Plant Genome Research (NIPGR), and is currently President of the Indian Botanical Society and Vice-President of the National Academy of Sciences, India.

A Fellow of all major Indian science academies and the Linnean Society of London, Prof. Barik is the recipient of several prestigious honours, including the Samanta Chandra Sekhar Award, Professor Birbal Sahni Medal, Prof. R.N. Tandon Memorial Award, Dr. Brandis Award, and Dr. Mopuri Brahmam Memorial Award for his outstanding contributions to plant sciences, biodiversity conservation, and ecological research.

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Restoring degraded ecosystems and recovering threatened plants in Himalayas: translating theory into practice

INTRODUCTION

India's commitment to the Bonn Challenge (that aims at a global goal to bring 350 million ha of degraded and deforested landscapes into restoration by 2030), was evident from their pledging a record breaking 26 million ha restoration target at the 14th Conference of the Parties (COP14) to the United Nations Convention to Combat Desertification (UNCCD), held in 2019 (<https://www.bonnchallenge.org/resources/india-brings-over-21-million-hectares-land-under-restoration-under-bonn-challenge>). As on 17 June, 2026, the World Day to Combat Desertification and Drought, India had already put 21.76 million ha of land under restoration efforts (<https://www.pib.gov.in/PressReleasePage.aspx?PRID=2273884®=3&lang=1> downloaded on 5th September, 2026). While the overall achievement is impressive, the restoration efforts must strategize the on-going programmes in such a manner that the restored ecosystems or landscapes recover the species populations once thriving the habitats making it species diverse with a focus on the lost threatened plant populations, regain vegetation stratification and other community attributes, and sustain effective ecosystem functioning so that the flow of ecosystem services remains uninterrupted. Therefore, any meaningful restoration strategy should ideally include interventions at populations, communities and ecosystem levels.

The author, along with his research group at

NEHU, Shillong, has been working for the past four decades to restore the degraded ecosystems/landscapes of north-east India and Eastern Himalaya following this three-layer intervention approach i.e. at population, community and ecosystem levels as per the requirements of the specific ecosystems/landscapes. In this presentation, landscape level restoration efforts have been exemplified by the restoration of degraded grassland and forest ecosystems in Cherrapunji plateau, degraded primarily due to coal mining and deforestation, respectively. Although varying in extent among the states and showing a declining trend over the years, shifting cultivation with shortened 'jhum cycle' continues to be one of the prime drivers of land degradation in north-east India (Table 1), impacting the community dynamics and ecosystem functioning in region's forested landscapes. Many factors including the climate change have been responsible for pushing several species to the brink of extinction by reducing their population size below the critical threshold level and impacting drastically their metapopulation dynamics. Before designing any restoration strategy, understanding the natural recovery pattern and processes at the stated three levels is a pre-requisite. Such understanding was achieved by the authors through their extensive analytical works in diverse shifting cultivation systems, forest ecosystems at different stages of degradation exposed to varying levels of disturbances, and coal-mine affected grassland, agriculture, and forest ecosystems (Mylliemngap et al. 2015 and Mylliemngap and Barik 2019). Following the results of such crucial studies which were conducted at different temporal and

spatial scales (Upadhaya et al. 2009, Ralte et al. 2005, Barik et al. 1996a and b, Sharma and Barik 2011) eco-restoration/recovery strategies were formulated using the identified successional/recovery pathways, organisms involved, and the deep understanding of community and population dynamics. These understandings led to the development of technologies which were science-based, cost-effective, and scalable. Such technologies were demonstrated in the field with active participation of the respective stakeholders i.e. farmers in case of shifting cultivation, coal mine owners in case of AMD, and forest officials in case of threatened plant conservation. In this paper, I present: (i) the results of such basic research, which formed the foundational bed rock of formulating the restoration strategies; and (ii) the restoration case studies representing interventions at population, community and ecosystem levels which were implemented in the field with definite outcomes.

Triple Environmental Challenges of north-east India

Shifting cultivation

Despite significant economic progress, shifting cultivation continues to be the

main source of livelihood for several tribal families of north-east India. The lack of updated and authentic data on the area under shifting cultivation as well as the total number of households practicing shifting cultivation in north-east hinders the effective management of shifting cultivation. Nevertheless, the available data shows a declining trend in shifting cultivation area in the north-east (Table 1). Considering the extent of geographical area that is affected by the shifting cultivation, it is required to develop sustainable strategy to manage such areas. The agrotechnology that needs to be developed to sustainably manage shifting cultivation is to meet the nutrient management challenge that becomes crucial at the end of the second year cropping. Depletion of nutrients to negligible levels at the end of the second year cropping forces the farmer to slash a new patch of forest for cultivation. Therefore, there is a need to develop a technology that does not force the farmers to shift to a new plot of forested land rather in the same plot of land he continues to cultivate year after year by maintaining the soil nutrient levels without compromising with the land productivity.

Table 1: Declining trend in area (ha) under shifting cultivation in different states of north-east India compared to the year 2003 (Source: Wasteland Atlas of India 2005, 2010, 2011 and 2019)

States	2003	2005/06	2008/09	2015/16
Arunachal Pradesh	111691	102506	85474	50909
Assam	43589	16004	8201	5261
Manipur	63147	75210	29667	49996
Meghalaya	62721	25585	28175	23775
Mizoram	114695	102853	60208	69156
Nagaland	111660	123908	141452	97933
Tripura	28489	8928	3030	3062
TOTAL	535992	454994	356207	300092

Coal Mining

The Coal India Limited operates in the north-eastern states of Assam through its unit, the North Eastern Coalfields. Ministry of Coal has successfully facilitated the commencement of scientific coal mining in the State of Meghalaya. This marks a significant step forward in bringing regulated and environmentally sustainable coal mining

practices to India's North-East region. Two coal blocks in Meghalaya have begun production after receiving due approvals. (<https://www.pib.gov.in/PressReleasePage.aspx?PRID=2153719®=48&lang=2>). Nevertheless, the AMD management in small coal mines owned by the respective land owners continues to be a serious environmental challenge (Table 2 and Fig 1).

Table 2: Coal mine area in the years 2007 and 2017 at different locations of northeast India (FTR, Major Grant, NMHS, 2019)

Mining location	Area in sq.km (2007)	Area in sq.km (2017)	Area increase (in sq.km)
DilliJoypore	2.45	2.83	0.38
Makum	12.88	16.34	3.46
Mikir Hills	3.77	5.34	1.57
Balpakhrum	0.94	1.26	0.32
Darrengiri	11	11.94	0.94
Karaibari	1.26	2.2	0.94
Chyrmang	2.04	2.2	0.16
Iokshi	13.19	14.14	0.95
Malwar Lamare	14.46	16.02	1.56
Sutnga	2.04	2.51	0.47
Lumdidon	8.17	8.8	0.63
Mawbehlarkar	1.88	2.2	0.32
MawlongShela	1.6	1.92	0.32
Umreling	4.4	6.28	1.88
Borjan	1.92	2.2	0.28
Jhansi-Disai	1.29	1.57	0.28
Tiru Valley	1.26	3.77	2.51
Tuensang	1.01	1.18	0.17
Namchik Hamphuk	0.33	0.41	0.08
TOTAL	85.89	103.11	17.22

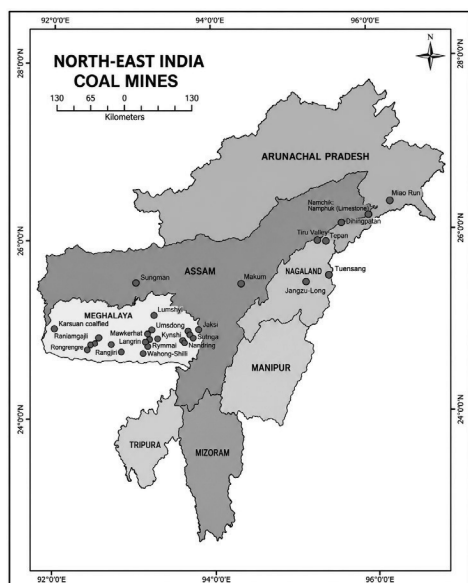


Fig 1: Locations and distributions of coalmines in northeast India (2017).

Biodiversity loss – Plants

A list of 2704 threatened plant species belonging to 1031 genera and 217 families was prepared by Barik et al. (2018). The list includes 2641 angiosperms, 23 gymnosperms and 44 pteridophyte species, and represents ~13% of the estimated vascular plant diversity in India. Orchids are the most vulnerable group of plants comprising 23% of the total threatened species followed by begonias (4%). An outcome of this is that the highest number of the threatened plants has been reported by Environmental Information System, MoEF&CC- ENVIS (1803) followed by Red Data Book (Shastri and Nair) - RDB (601), Appendices to Convention on International Trade in Endangered Species of Wild Fauna and Flora - CITES (572), Conservation Assessment and Management Plan Workshops - CAMP (494), International Union for Conservation of Nature - IUCN (473), National Biodiversity Authority- NBA (109), and Schedule-VI of Wildlife Protection Act - WPA (13) (Table 3).

Table 3: Number of species under different threat categories in India as reported by various agencies. (after Barik et al. 2018b).

IUCN	RDB	CAMP
Extinct – 5	Extinct – 1	Extinct – 2
Critically endangered – 39	Potentially extinct – 61	Critically endangered – 104
Endangered – 96	Endangered – 118	Endangered – 191
Vulnerable – 79	Vulnerable – 109	Vulnerable – 148
Near-threatened – 19	Rare – 237	Near-threatened – 36
Data-deficient – 12	Indeterminate – 72	Data deficient – 10
Least concern – 178	Insufficiently known – 2	Least concern – 2
Not assessed – 45	Data-deficient – 2	Not evaluated – 4
Total – 473	Total – 602	Total – 497
ENVIS	CITES	NBA
Extinct – 3	Appendix I – 11	Endangered – 106
Potentially extinct – 61	Appendix II – 532	
Critically endangered – 9	Appendix III – 5	
Endangered – 245	Total – 549	
Vulnerable – 105		Schedule VI
Indeterminate – 237		Endangered – 13
Rare – 958		
Rare, endangered, threatened – 183		
Total – 1801		

Considering the extent of forest area in the north-east, the number of threatened species as a proportion of total species reported in each state is alarming (Table 4).

It is essential to understand the natural recovery process of any community or ecosystem following the disturbances. The knowledge so generated helps in designing the recovery

Table 4: Taxon-wise threatened plants in different north-eastern states of India (after Barik et al. 2018b).

Sl. No.	Name of the State	No. of Families	No. of Genera	No. of Species
1.	Arunachal Pradesh	60	122	229
2.	Assam	51	104	195
3.	Manipur	27	48	113
4.	Meghalaya	63	128	284
5.	Mizoram	11	21	47
6.	Nagaland	18	39	95
7.	Sikkim	43	113	262
8.	Tripura	14	20	25

Understanding natural recovery processes and patterns

Recovery of communities and ecosystems during fallow period following the cropping phase of shifting cultivation

strategy. Even after 12 years of fallow period under shifting cultivation cycle, the species recovery remained abysmally low at 67% of the original species content, represented by an undisturbed forest community in the buffer zone of Nokrek Biosphere Reserve (Fig 2).

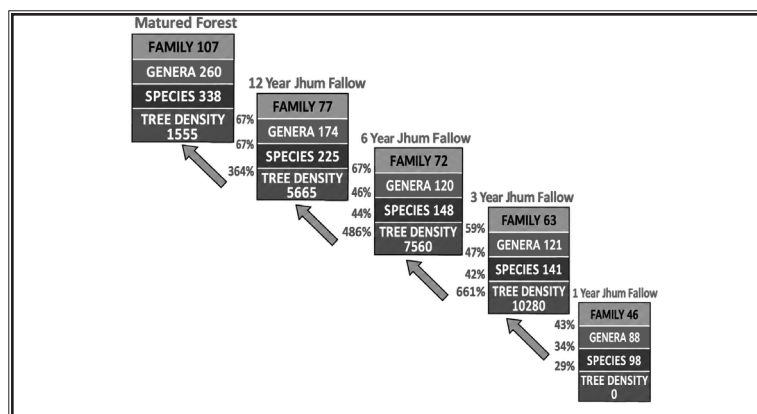


Fig 2: Recovery of plant species as per taxonomic hierarchy in communities during fallow period following the cropping phase in Nokrek Biosphere Reserve, Meghalaya.

The soil properties and some ecosystem functional indicators could recover up to 96% (e.g. Cation Exchange Capacity) while others could return up to 56% (Microbial

Carbon) and 61% (Microbial Nitrogen) only compared to those in the undisturbed natural forest, even after 12 years of fallow recovery process (Fig 3).

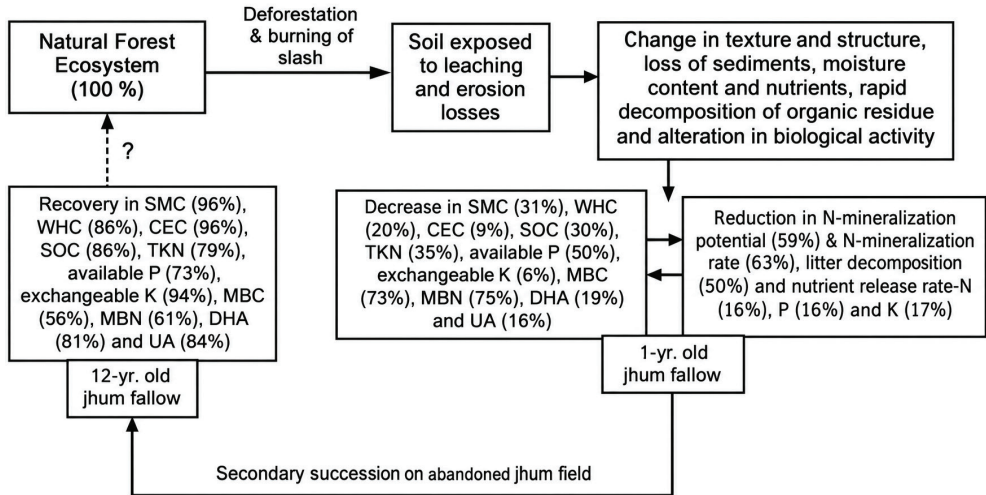


Fig 3: Changes in soil physicochemical characteristics and selected ecosystem functional indicators during the recovery of a shifting cultivation fallow (chrono sequence approach) in Nokrek Biosphere Reserve, Meghalaya.

Recovery of degraded forests after deforestation: species replacement pattern

The recovery process and pattern of a degraded sub-tropical broadleaved forest in Cherrapunji plateau were studied over a period of three years following chrono sequence approach. The composition of 5 dominant/co-dominant species in different triplicate forest stands varying in age of recovery revealed a distinct trend of species replacement during ecosystem recovery (Fig. 4). Among tree species, *Castanopsis purpurella* and *Lithocarpus dealbatus* were dominant throughout the period of recovery beginning from year 1, as sprouted stumps, through years 5 and 10 of recovery. These two species were also dominant in the UF stands. The TWINSpan classification revealed three indicator species each being unique to different forest stands of varying recovery ages (Fig. 5) (Mylliemngap et al. 2015).

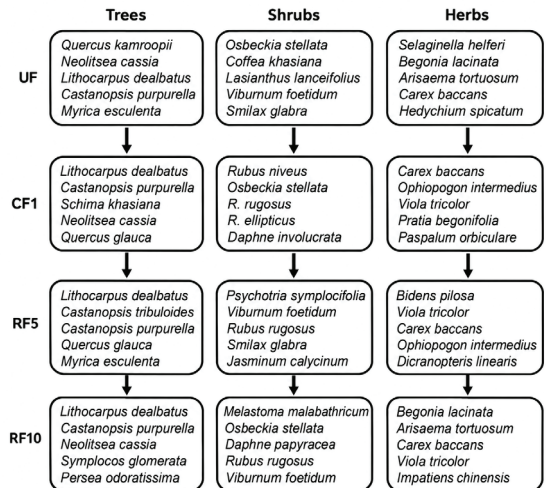


Fig 4: Five dominant and co-dominant tree, shrub and herb species colonizing the forest stands during different years of recovery (Mylliemngap et al. 2015)

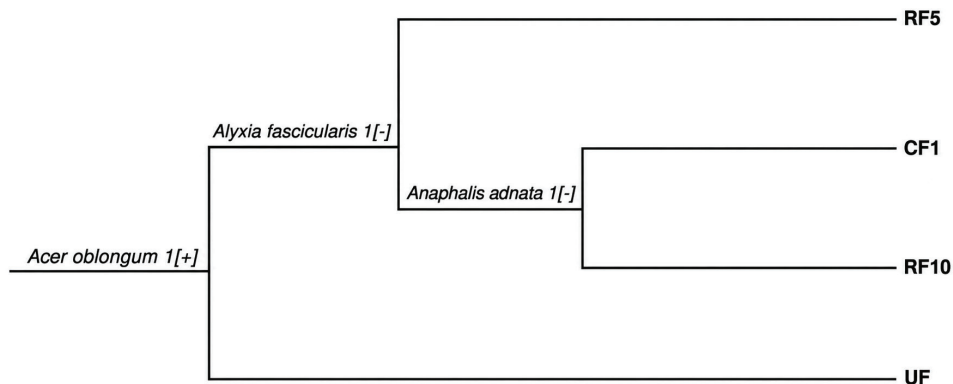


Fig 5: Dendrogram showing hierarchical levels of TWINSpan classification of the four forest stands with indicator species at each level of division. UF, old-growth undisturbed forests; CF1, 1-year-old; RF5, 5-year-old and RF10, 10-year-old recovering forest stands. (Mylliemngap et al. 2015)

Community dynamics in a grassland ecosystem as affected by coal mining

A chrono sequence study from Cherrapunji plateau revealed that plant diversity, net primary productivity and soil nutrient

contents of a humid subtropical grassland remained low even after 50 years of post-disturbance recovery from coal mining (Tables 5 and 6).

Table 5: Soil physico-chemical characteristics of the undisturbed grasslands, mining-affected and recovering grasslands (mean $\pm$ SE, n = 64). Within a row, values denoted with the same superscripts are not significantly different while those denoted by different superscripts are significantly different from each other according to Tukey's HSD test.

Soil parameters	US	MS	RG15	RG30
ST ($^{\circ}\text{C}$)	16.91 $\pm$ 1.62 ^a	17.48 $\pm$ 1.85 ^a	17.81 $\pm$ 1.58 ^a	18.28 $\pm$ 1.56 ^a
SMC (%)	24.65 $\pm$ 3.28 ^b	27.50 $\pm$ 2.61 ^a	16.65 $\pm$ 1.91 ^c	14.92 $\pm$ 3.16 ^c
Soil pH	5.04 $\pm$ 0.19 ^a	3.99 $\pm$ 0.23 ^b	5.39 $\pm$ 0.21 ^a	5.22 $\pm$ 0.33 ^a
CEC (cmol 100 g ⁻¹)	0.288 $\pm$ 0.010 ^b	0.566 $\pm$ 0.060 ^a	0.101 $\pm$ 0.010 ^c	0.087 $\pm$ 0.020 ^c
SOC (%)	1.93 $\pm$ 0.04 ^b	2.68 $\pm$ 0.17 ^a	1.26 $\pm$ 0.19 ^c	1.18 $\pm$ 0.11 ^c
TKN (%)	0.28 $\pm$ 0.012 ^b	0.35 $\pm$ 0.024 ^a	0.15 $\pm$ 0.019 ^c	0.13 $\pm$ 0.014 ^c
P _{av} ($\mu\text{g g}^{-1}$)	0.666 $\pm$ 0.010 ^a	0.906 $\pm$ 0.060 ^a	0.083 $\pm$ 0.011 ^b	0.104 $\pm$ 0.011 ^b
K _{av} ($\mu\text{g g}^{-1}$)	321.10 $\pm$ 21.13 ^a	304.00 $\pm$ 31.39 ^a	159.38 $\pm$ 11.40 ^b	159.37 $\pm$ 15.68 ^b
Na _{av} ($\mu\text{g g}^{-1}$)	72.29 $\pm$ 2.25 ^a	52.81 $\pm$ 1.84 ^b	36.55 $\pm$ 2.37 ^c	24.17 $\pm$ 1.93 ^d
Ca _{av} ($\mu\text{g g}^{-1}$)	42.58 $\pm$ 3.70 ^a	40.55 $\pm$ 6.61 ^{ab}	51.23 $\pm$ 6.69 ^a	31.69 $\pm$ 5.74 ^b
Mg _{av} ($\mu\text{g g}^{-1}$)	15.78 $\pm$ 1.33 ^a	13.56 $\pm$ 1.62 ^a	13.19 $\pm$ 1.68 ^a	8.76 $\pm$ 1.23 ^b

(Source: Mylliemngap and Barik 2019.)

Table 6: Biomass, annual net primary productivity, turnover rate and turnover time in the grasslands of different recovery ages.

Compartments	UG	MG	RG15	RG50
Biomass (g m⁻²)				
Live shoot	176.66 ± 15.2 ^a	23.44 ± 2.0 ^d	73.63 ± 3.4 ^c	122.50 ± 8.2 ^b
Dead shoot	28.44 ± 5.7 ^a	10.11 ± 1.3 ^b	39.86 ± 7.9 ^a	24.40 ± 6.0 ^a
Fine roots	1499.04 ± 112.9 ^b	1002.17 ± 68.8 ^b	981.50 ± 95.0 ^a	944.58 ± 61.3 ^a
Coarse roots	210.96 ± 37.1 ^b	191.04 ± 30.1 ^b	227.67 ± 30.3 ^b	359.46 ± 49.8 ^a
Total	1915.11	1226.76	1322.66	1450.94
Net annual primary productivity (g m⁻² year⁻¹)				
Live shoot	425.30	40.11	80.21	312.51
Fine roots	1213.00	1002.17	1496.17	1262.00
Coarse roots	434.17	402.13	362.29	544.29
Total	2072.47	1444.41	1938.67	2118.80
Turnover rate (year⁻¹) and turnover time (years)				
Turnover rate				
Shoot	2.45	0.30	2.06	2.08
Root	0.38	0.52	0.70	0.68
Turnover time				
Shoot	0.41	3.33	0.49	0.48
Root	2.60	1.93	1.43	1.47

The values represent mean ± S.E. Within a row, values denoted with the same superscripts are not significantly different while those denoted by different superscripts are significantly different from each other according to Tukey's HSD test

(Source: Myllemngap and Barik 2019)

Factors declining the populations of threatened plant species

The populations of threatened plants are continuously declining worldwide due to natural and anthropogenic causes. Understanding these causes and addressing them effectively as preventive measures in a timely manner is the first step towards conservation of these species. Habitat loss due to agriculture, urban growth and infrastructure development has been the prime factor of species loss. The native habitats of the species get degraded or altered often through conversion of the whole ecosystems such as forests, grasslands and wetlands into a completely new ecosystem. The continuity of the habitats is frequently disrupted through ecosystem fragmentation. Such alterations

negatively impact natural seed dispersal and plant regeneration. Climate change compounds this problem by altering micro-climate and habitat conditions of threatened plants largely due to change in temperature and precipitation patterns. Increased occurrence of fire in several ecosystems further aggravates the species survival. Although a few species can relocate themselves to favourable habitat and climatic conditions, most fail to keep the pace of migration needing 'assisted migration'. Very few adapt to the changed climatic and habitat features, risking several species to climate-related extinction. Invasive species outcompeting local plants and occurrence of plant diseases are the other threats, which often get accelerated with global environmental change. Inherent reproductive

bottleneck, over-exploitation of certain species for human consumption, over-grazing, and genetic drift following reduced population size beyond a critical limit are the other factors risking several species to extinction.

Considering the cost involved in conservation actions for the threatened species, it is required to determine which species require immediate assistance i.e. the process of conservation prioritization. This is the second most important step in conservation action that needs to be precisely undertaken along with correct threat classification. Generation of population data and trend through extensive (for determining population status) and intensive (extinction risk assessment) population survey is key to this process. The threats, and the speed of species decline are ascertained. Unfortunately, such data are scarce for most threatened plants of India hindering the prioritization process.

Since its establishment in 1964, the International Union for Conservation of Nature's Red List of Threatened Species (IUCN-Red List) has been evolving to become the world's most comprehensive information source on the global extinction risk status of animal, fungus and plant species. Besides threat classification, the continuously updated Red List also tracks extinction risks of more than and coordinates worldwide habitat protection and targeted recovery actions (<https://www.iucnredlist.org/about/background-history> downloaded on 5th September, 2026). It has put 38% of known tree species under high extinction risk category. As of 2026, the IUCN Red List of Threatened Species includes assessments for over 78,400 plant species, which is approximately 18% of the world's known plant life. Realizing this, IUCN has recently taken steps to rectify the biases in threat assessment with special initiatives for plants and fungi similar to animals those were taken earlier. More than 23,000 plant species

have been formally classified under threat tiers (Vulnerable, Endangered, or Critically Endangered).

New tools and innovative approaches

Improved shifting cultivation models: SWEET

Several models appropriate to local socio-geographic conditions have been tried in the past as an alternate to shifting cultivation in different states of north-east India. Some of these are, ICAR three-tier model, a topography-based land use model with agri-horti-silvipastoral systems, New land use policy of Mizoram, and Village relocation plan duly supported by cash crops such as rubber plantations in Tripura. However, most of these initiatives could not succeed due to slow or non-acceptability by the people. Therefore, green terrace/hedge row-based land use models based on Sloping Watershed Environmental Engineering Technology (SWEET) were developed in low and mid-elevation mountain areas of Eastern Himalaya in Arunachal Pradesh. The models showed improved nutrient status with aging and were successful in continuing the cultivation in the same plot beyond three years. Unlike the shifting cultivation plots, the net income kept on increasing from second year onwards (Table 7) and soil properties were significantly improved.

Converting Shifting cultivation plots to settled cultivation through four-tier models with site-specific bio-inoculants

Elevation and tribe-specific four-tier agroforestry models were developed by planting species of farmer's choice targeting to meet all his requirements. This included top canopy layer tree species having use values such as *Parkia timoriana*, *Artocarpus integrifolia*, *Aquilaria malaccensis*, *Delinia indica*, *Moringa oleifera*, *Phyllanthus emblica*, *Litchi chinensis* etc. Middle tree layer consists of fruit plants such as pine

Table 7: Three-year economics of jhum vs. Sloping Watershed Environmental Engineering Technology models.

Sites/Plot	Year	Gross income (Rs/ha)	Cost of cultivation (Rs/ha)	Net income (Rs/ha)	Return per Rupee invested
Julie/SWEET	1st year	6060	16870	- 10810	0.36
	2nd year	9770	12470	- 2700	0.78
	3rd year	22145	3000	+ 19145	7.38
	3 year Total	37975	32340	+ 5635	1.17
Julie/Jhum	1st year	14950	11244	+ 3706	1.33
	2nd year	11230	8800	+ 2430	1.28
	3rd year	8940	9363	- 423	0.95
	3 year Total	35120	29407	+ 5713	1.19
Yazali/SWEET	1st year	3780	16870	- 13090	0.22
	2nd year	6962	11370	- 4408	0.61
	3rd year	16710	3000	+ 13710	5.57
	3 year Total	27452	31240	- 3788	0.88
Yazali/Jhum	1st year	9678	9883	- 205	0.73
	2nd year	6438	8090	- 1652	0.80
	3rd year	5854	7968	- 2114	0.73
	3 year Total	21970	25941	- 3971	0.85

apple, mango, coconut, areca nut (with black pepper as creeper), papaya, guava, orange etc. Maize and rice as staple crops along with jhum vegetable crops with dominance of legumes constituted the third layer. Ginger, turmeric, *Colocasia* and *Amorphophallus* constituted the below ground layer. While selecting the

species and designing the models, canopy architecture and other attributes of tree species suitable for agro-forestry and inter/intra-crop competition were kept in mind. Appropriate soil and moisture conservation measures such as half-moon terraces were made along with tree plantation. Bacterial isolates were collected

from soil samples of shifting cultivation plots, screened and tested for plant growth promoting (PGP) properties with seed germination and pot experiments. Biofertilizers with *Rhizobium* and phosphorus solubilizing bacteria were

developed and were tested on the field. Field trials showed positive result in the yield data. The methods of preparation of such biofertilizers at small scale were demonstrated to farmers (Fig 6).

Bio-fertilizer field trials in the model plots in different states

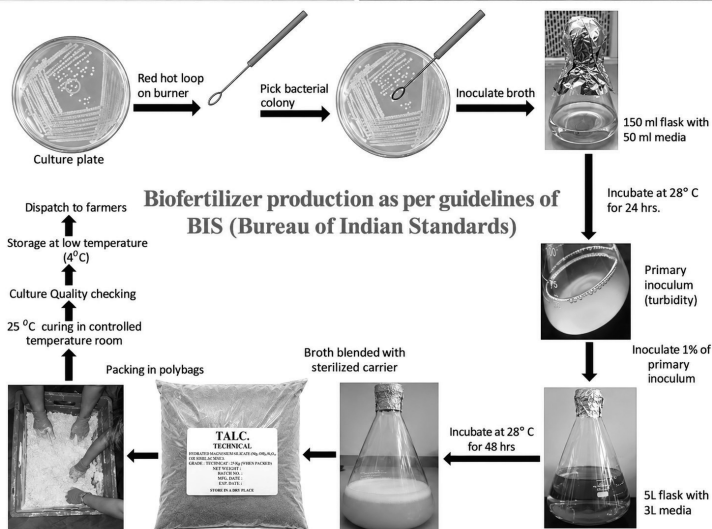


Fig 6: Site-specific biofertilizers developed and farmers trained for small-scale production.

Acid Mine Drainage treatment model for small coal miners

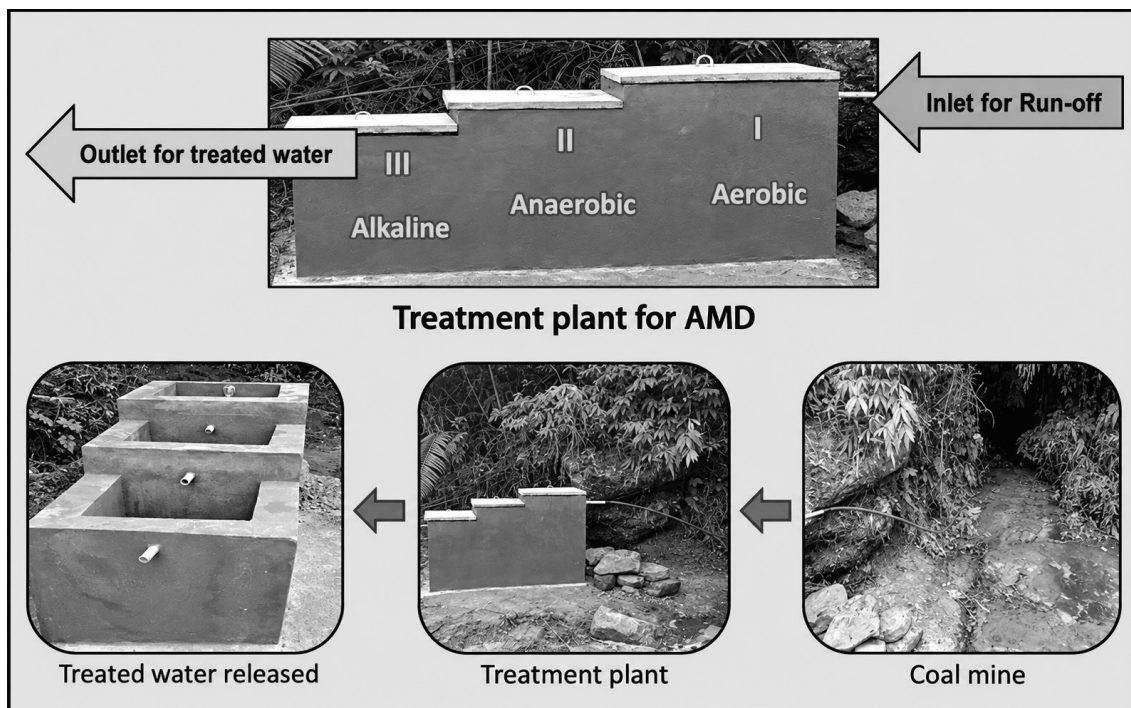


Fig 7: A prototype model for treatment of coal mine water and AMD from small coal mines of Meghalaya.

An AMD treatment model was developed by designing a pilot scale treatment plant and constructing the same on-site in the coal mine areas (Fig 7). This comprised of

three sequential sections so that the effluents (AMD) from the coal mines pass through these three compartments of the prototype model before being released into the surroundings.

Table 8: pH neutralization of AMD using the bacterial consortium and limestone in the prototype

Treatment	pH changes			
	Control	1st Day	2nd Day	3rd Day
Tank with consortium	3.28	4.12	4.57	5.9
Tank with consortium and limestone	3.30	5.5	5.6	6.4

The two microbial consortia (aerobic and anaerobic) in the first two chambers were the main active treatment ingredients, which were native bacteria analyzed for their ability to generate alkalinity in a medium while being able to survive in the presence of heavy metals to bioremediate. The strains were identified following biochemical and molecular approaches. Locally available limestone bed was used in the third chamber as the passive treatment support. The total cost of the pilot plant was less than Rs. 50, 000/-. The bacterial consortia (in aerobic and anaerobic chambers) have abilities to increase the pH of AMD up to 5.9 in 3 days under active treatment, and with limestone chamber (passive) up to 6.4 (Table 8).

Threatened plant conservation

Besides in situ protection such as safeguarding ecosystems comprising the native habitats of threatened plants, ex situ conservation actions such as fast/advanced multiplication approaches, botanical gardens, seed banks, and cryopreservation need to be taken up to protect species with small wild populations. New initiatives with targeted actions, prioritized species and technology inputs need to be taken up as more than half of threatened plants need such direct and hands-on recovery works as reintroductions and disease management. Although significant ex situ collection efforts such as seed banks or botanical gardens have been made, that help preserve and propagate plants beyond their native habitats and produce seeds or seedlings for re-introduction, in situ actions with appropriate technology inputs in their natural habitats would ensure their sustainable populations and self-perpetuation in future.

The conservation objectives for threatened plants are most efficiently achieved when

optimal understanding of threats and their elimination strategy is put into practice. Also “the small population paradigm” or “the conservation genetics paradigm” is integrated with “habitat quality paradigm”. Keeping these two points in mind, a pan-India threatened plant conservation programme was conceptualized and implemented covering 70 threatened plant species with funding support from DBT, Ministry of science and Technology, Government of India. The programme was initiated in the year 2012 and completed in 2019 involving 150 scientists in 37 institutions across the country. The Himalayan species and the species from the other biodiversity hotspots were in focus. The programme followed the following steps:

1. Discovery of a new species must follow ascertaining its conservation status

Most new species discovered belong to one or the other threat category. Thus, it was imperative to assess their threat status critically for their effective conservation. For example, “the genus *Aconitum* was surveyed extensively in the Eastern Himalayan region and north-east India from 2016 to 2018. The Extent of Occurrence (EOO) for *A. haridasanii* was only 0.13 km² and Area of Occupancy (AOO) was 0.02 km². Two populations were located in the Shuguster lake and Taktsang Chu area at an elevation range of 3678-3798 m. Extreme year to year fluctuation in the number of individuals was recorded during the study period. The habitat of the species is threatened by habitat fragmentation, tourism, road construction and other development activities. The grazers and shepherds also selectively uproot the species from pastures to prevent accidental cattle poisoning and death. The extraction of the species owing to its medicinal importance is another key factor for its population depletion. All these factors have contributed to the very low population size of the species. The number of matured individuals

in both populations ranged from 15-20 individuals i.e., <50 individuals. The new species was categorized (following IUCN 2017 version 13) as Critically Endangered B1b(i,ii,iii,v) c(i,ii,iii)+2b(i,ii,iii,v)c;C2a(i);D" (Tiwary et al. 2020).

2. Ascertaining the correct taxonomic status of threatened plants

The taxonomic identity of each target species was verified through integrated examination of field-collected specimens, herbarium materials, protologues, type descriptions and relevant taxonomic literature.

3. Discovery of new populations and species using Ecological Niche Modelling (Adhikari et

al. 2018)

Existing occurrence records of the target species were compiled from field surveys, herbarium specimens, published literature, biodiversity databases and authenticated institutional records. All occurrence points were georeferenced and subjected to taxonomic and spatial validation. Duplicate records, records with uncertain identification and points with inadequate geographic precision were removed. Spatial thinning was applied, where required, to minimize sampling bias and spatial autocorrelation. Ecological Niche Models were developed using relevant climatic, topographic, edaphic, hydrological, vegetation and land-use variables. New populations were predicted and located through the models (Fig 8).

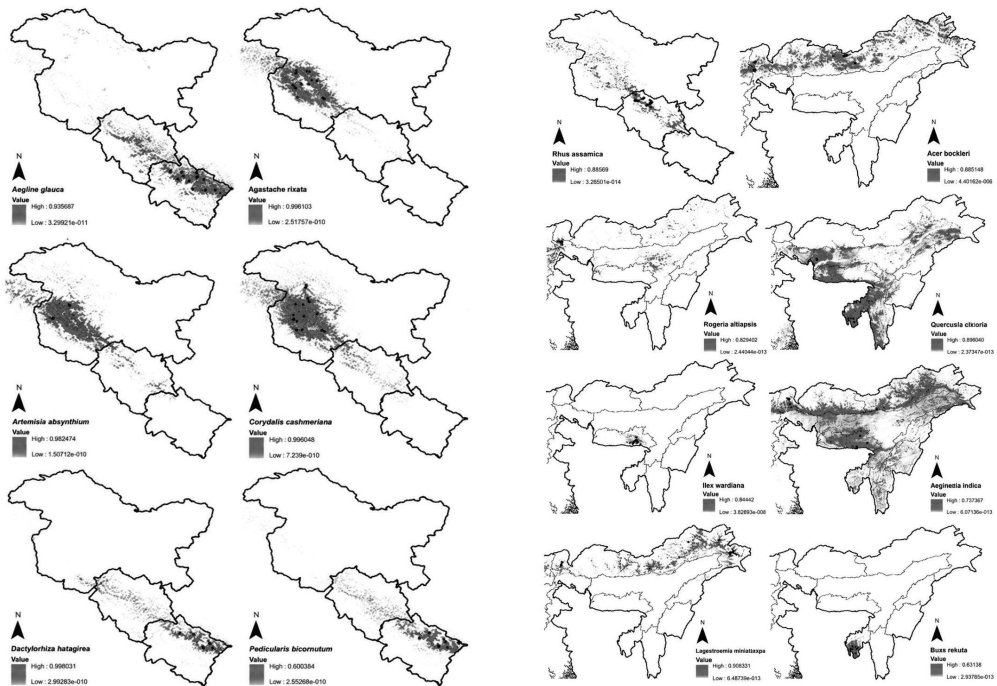


Fig 8: ENM for locating new populations in north-east and Kashmir Himalayas. (Adhikari et al 2018).

4. Current distribution mapping and assessment of the impact of climate change on species distribution (Singh et al. 2023)

The current distribution of each target species was mapped by integrating verified occurrence records, systematic field observations, herbarium records and remote-sensing-derived environmental information. Geographic coordinates, elevation, habitat type, land-use category, associated vegetation and disturbance conditions were recorded for each occurrence. Current distribution maps were prepared in a Geographic Information System.

The Area of Occupancy and Extent of Occurrence were calculated following the IUCN guidelines. Area of Occupancy was estimated using the recommended grid-based approach, while Extent of Occurrence was derived from the

minimum convex polygon enclosing the verified occurrences. Distributional fragmentation, number of locations and degree of isolation among populations were assessed.

Climate-change impacts were evaluated by projecting validated ecological niche models under selected CMIP6 climate scenarios. Predictions from multiple General Circulation Models were combined to reduce dependence on a single climate model. Changes in suitable habitat were quantified as habitat loss, habitat gain, habitat persistence and potential range shift. Elevational and geographic shifts in suitable habitat were also assessed. Stable areas predicted to remain suitable under multiple scenarios were identified as climate refugia and prioritised for in situ conservation, population reinforcement and reintroduction.

Table 9: Criteria of threat classification IUCN (Version 3.1)

	Critically endangered	Endangered	Vulnerable
B. Geographic range in the form of either B1 (extent of occurrence) and/or B2 (area of occupancy)			
B1 Extent of occurrence (EOO; sq. km)	<100	<5000	<20,000
B2 Area of occupancy (AOO; sq. km) and at least two of the following three conditions:	<10	<500	<2000
(a) Severely fragmented or number of locations	–1	≤5	≤10
(b) Continuing decline observed, estimated, inferred or projected in any of (i) extent of occurrence, (iii) area of occupancy, (iii) area, extent and/or quality of habitat, (iv) number of locations or subpopulations and (v) number of mature individuals.			
(c) Extreme fluctuations in any of (i) extent of occurrence, (ii) area of occupancy, (iii) number of locations or subpopulations, (iv) number of mature individuals.			
C. Small population size and decline			
Number of mature individuals and at least one of C1 and C2	<250	<2500	<10,000
C1 Observed, estimated or projected continuing decline of at least (up to a maximum of 100 years in future):	25% in three years or one generation (whichever is longer)	20% in five years or two generation (whichever is longer)	10% in ten years or three generation (whichever is longer)
C2 Observed, estimated, projected or inferred continuing decline and at least one of the following three conditions:			
(a) (i) Number of mature individuals in each subpopulation	≤50	≤250	≤1000
(ii) Percentage of mature individuals in one subpopulation	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals			
D. Very small or restricted population			
D1 Number of mature individuals	<50	<250	D1. 1000
D2 Only applies to the VU category	–	–	D2. Typically: AOO <20 sq. km or number of locations ≤5
Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time.			

VU, Vulnerable; CR, Critically endangered; EX, Extinct.

5. Assessment of population size and trend

All known and newly discovered populations of the target species were surveyed using growth-form-specific sampling methods. Population trends were categorised as increasing, stable, declining or uncertain, with the supporting evidence documented for each classification.

6. Correct threat classification based on population data (Barik et al. 2018a)

Threat assessment was undertaken using the latest IUCN Red List Categories and Criteria. The assessment considered population reduction, restricted geographic range, AOO, EOO, small population size, continuing decline, severe fragmentation, extreme fluctuations and quantitative estimates of extinction risk under Criteria A–E (Table 9).

7. Technology development for propagation (Panda et al. 2018)

Propagation protocols were developed using seeds, vegetative propagules or tissue-culture techniques, depending on the reproductive

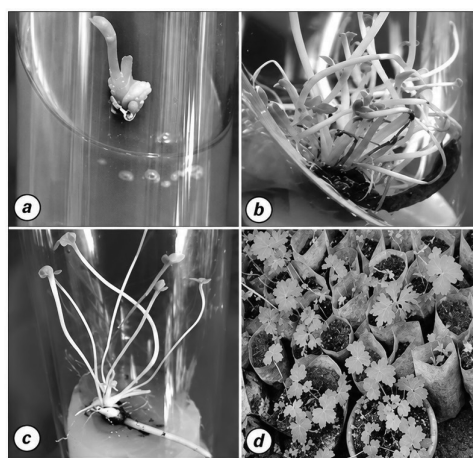
biology and conservation requirements of each species (Fig 9). The most effective protocols were validated under nursery conditions. Standard Operating Procedures were prepared for seed collection, pretreatment, propagation, nursery management, hardening, transport and field establishment.

8. Reintroduction following habitat-suitability mapping

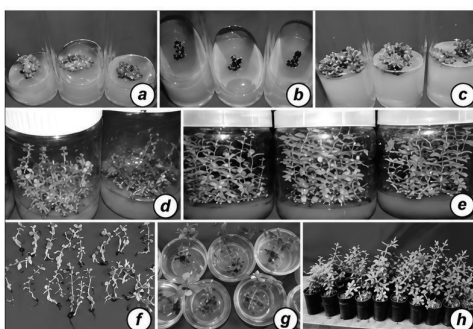
Potential reintroduction sites were identified using species-specific habitat-suitability models developed from climatic, topographic, soil, hydrological, vegetation and disturbance variables. Sites were screened for current suitability, future climatic stability, land tenure, habitat integrity, connectivity, protection status and feasibility of long-term management.

9. Metapopulation modelling for estimating extinction probability and determining the optimum number of seedlings to be planted (Lyngdoh et al. 2018)

Natural populations are represented as spatially



Different *in vitro* propagation stages of *Aconitum nazarum*. **a.** Excised shoot bud cultured on initiation medium showing signs of morphogenetic response by releasing the meristematic loci. **b.** Multiple shoots/micro-shoots developed in culture. **c.** Rooted plant. **d.** Regenerates transplanted in potting mix maintained in the polyhouse.



Direct plant regeneration of *Hypericum gayti*. **a, b.** Proliferation of leaf (**a**) and intermodal explants (**b**) grown on MS medium supplemented with 1.0 mg l^{-1} BA after 4 weeks of culture. **c, d.** Development of shoots from intermodal and leaf explants on MS medium supplemented with 1.0 mg l^{-1} BA and 3% sucrose after 4 weeks of subculture. **e.** Elongation of shoots on MS liquid medium supplemented with 1.0 mg l^{-1} BA and 3% sucrose after 4 weeks of third subculture. **f.** Induction of roots from micro-shoots on half-strength MS medium supplemented with 1.0 mg l^{-1} IBA and 2% sucrose after three weeks of culture. **g.** *In vitro* raised plantlets acclimatized in distilled water and ready for transfer to greenhouse. **h.** *In vitro* raised plants grown in the green house after 2 months of transfer.

Fig 9: Macro and Micro propagation methods applied.

discrete habitat patches connected through potential dispersal. For each population, data on patch size, carrying capacity, abundance, stage structure, recruitment, mortality, reproductive output, dispersal distance, habitat quality and disturbance frequency were compiled.

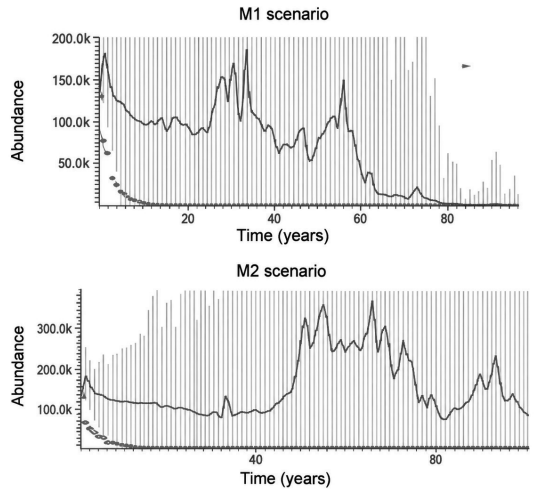
Population viability and metapopulation models were developed using stage-structured matrix models, stochastic simulation or suitable spatially explicit modelling platforms. Transition probabilities among seedling, juvenile and adult stages were estimated from field observations, published information and propagation or reintroduction trials. Environmental and demographic stochasticity, catastrophes, habitat decline and climate-related changes were incorporated where data permit.

Alternative management scenarios were simulated, including no intervention, population reinforcement, establishment of new subpopulations, different planting sizes, repeated planting and improvement of connectivity. Extinction probability, expected population size, time to extinction, probability of population persistence and sensitivity to demographic parameters were estimated over appropriate time horizons (Fig 10).

The optimum no. of seedlings was determined by identifying the minimum planting size that achieves a predefined probability of persistence under realistic mortality and disturbance conditions.

10. Herbarium preparation

Representative voucher specimens were collected from natural populations, were processed following standard herbarium



Comparison of expected metapopulation change in M1 and M2 scenarios over 100 years. The mean and 95% confidence intervals of the means after 1000 replications are presented. Minimum and maximum populations are represented by red arrows. Some of the maximum confidence intervals and range are not shown to confine the scale of the curve for better representation.

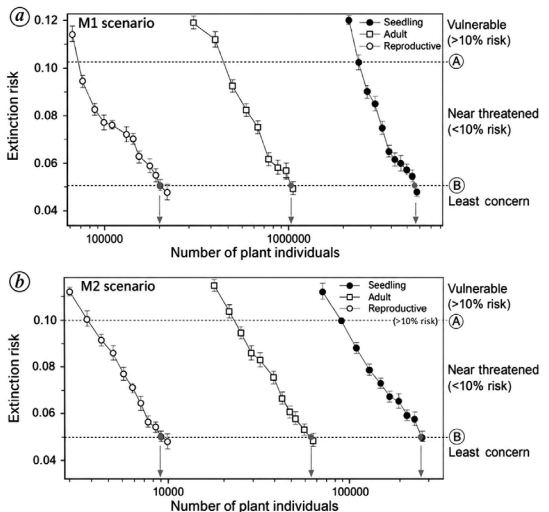


Fig 10: Metapopulation modeling outputs.

procedures, including pressing, drying, poisoning or disinfestation where required, mounting, labelling and accessioning.

11. Establishment of a threatened plant conservatory

A threatened plant conservatory was established as an ex situ conservation facility at CSIR-NBRI (Haridasan et al. 2018).

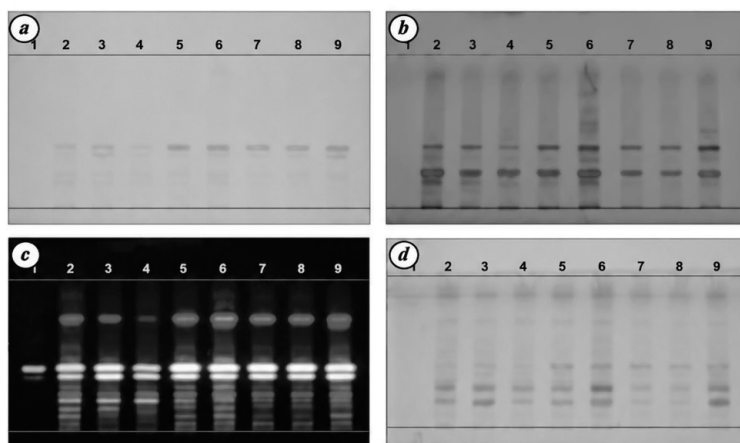
12. Bioprospecting of selected species: Conservation through sustainable uses

Bioprospecting was undertaken only for

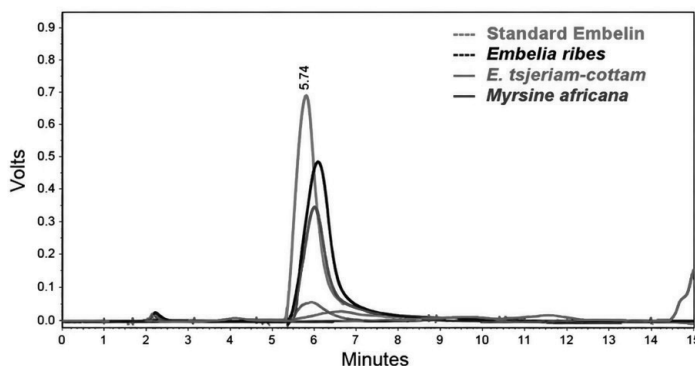
selected species (Fig 11) and in accordance with applicable biodiversity, access and benefit-sharing and institutional regulations (Venkatsubhramanyam et al. 2018).

13. Genetic enrichment of selected species following genetic-diversity studies (Chrungoo et al. 2018)

Genetic diversity was assessed across



HPTLC fingerprint of *Berberis* spp. (methanol extract; mobile phase: *n*-butanol : glacial acetic acid : water 7 : 1.5 : 2) ratio visualized under (a) white light, (b) UV 254 nm, (c) 366 nm, and (d) after derivatization with anisaldehyde-sulphuric acid reagent. Lane 1, Berberine standard (R_f 0.42); lanes 2–4, *Berberis aristata*; lanes 5 and 6, *Berberis asiatica*; lanes 7 and 9, *Berberis lycium* showing the presence of berberine.



HPLC profile of *E. ribes*, *E. tsjeriam-cottam* and *Myrsine africana* with standard embelin. Overlay of HPLC profiles of the methanolic extracts of *E. ribes*, *E. tsjeriam-cottam* and *Macsa indica* with standard embelin. Column: C18 column (Kromasil, 250 × 4.6 mm); mobile phase: methanol : water : acetic acid : tetrahydrofuran (85 : 15 : 3 : 1) v/v/v/v; flow rate: 1.6 ml/min; 288 nm.

Fig 11: Bioprospecting HPTLC and HPLC outputs.

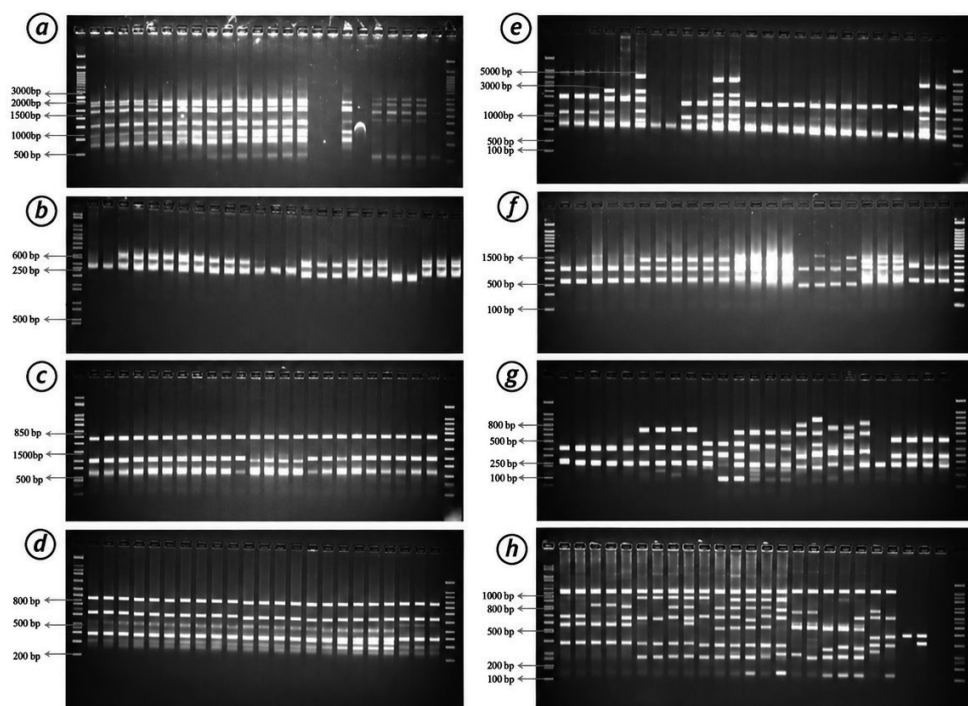
representative populations of selected species. Genetic enrichment was undertaken through carefully planned reinforcement or crossing among compatible individuals and populations (Fig. 12).

14. Addressing reproductive bottleneck

Reproductive biology studies were undertaken for the species to understand the failure to produce seeds.

Nucleotide sequence analysis with respect to the *matK* region of *Embelia ribes*, *Embelia floribunda* and *Embelia subcoraceae* from populations located in Meghalaya and Arunachal Pradesh

<i>matK</i>	Taxon	Indels	Sequence divergence (%)	CS (%)	VS (%)	PIS (%)	SS (%)	ii	si	sv	R (si/sv)
	<i>E. ribes</i> + <i>E. subcoraceae</i> + <i>E. floribunda</i>	0	4.09	86.67	13.32	11.23	2.08	828	15.00	21.0	0.70
	<i>E. ribes</i>	0	2.56	92.35	7.64	5.90	1.73	841	9.00	13.0	0.75
	<i>E. subcoraceae</i>	0	1.22	96.75	3.24	1.96	1.27	852	3.00	7.0	0.43
	<i>E. floribunda</i>	0	0.11	99.76	0.23	0.00	0.23	563	38.00	47.0	0.80



Agarose gel electrophoresis profile of ISSR amplification in *Embelia ribes*, *Embelia floribunda* and *Embelia subcoraceae* from Meghalaya and Arunachal Pradesh. Amplification profile with (a-h) primers: a, ISSR809; b, ISSR810; c, ISSR819; d, ISSR826; e, ISSR834; f, ISSR842; g, ISSR857; h, ISSR859. Ladder M, 50 bp/100 bp represented in left side and 1st well of all gel pictures.

Fig 12: Genetic diversity study for genetic enrichment in *Embelia* species.

CONCLUSION

All the above three technologies to mitigate the three identified environmental challenges have been piloted and tested successfully at different scales. These need to be further upscaled and adapted to new areas taking care of local factors, as per the requirement. Effective awareness and training activities to popularize the technologies will hold key to their successful upscaling.

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G.B. Pant Memorial Lectures

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Dr. M.S. Swaminathan, Director, CRSARD,
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Dr. T.N. Khoshoo, Jawaharlal Nehru Fellow, TERI, New
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Mr. V. Rajagopalan, Vice President, World Bank,
Washington - 1993

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Prof. U.R. Rao, Member, Space Commission,
New Delhi - 1994

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Bangalore - 1996

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JNCASR, Bangalore - 1997

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Prof. J.S. Singh, Emeritus Professor, BHU,
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Prof. Madhav Gadgil, Centre for Ecological Sciences, IISc,
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Dr. S.S. Handa, Ex-Director, PRL (CSIR),
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Dr. Lalji Singh, Director, CCMB, Hyderabad - 2007

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Dr. R.S. Tolia, Chief Information Commissioner, Govt. of
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Prof. V. Nanjundiah, JNCASR, Bangalore - 2011

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Dr. Gopal Singh Rawat, formerly Dean and Director at the
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