Widespread gaps in native tree seed supply for ecosystem restoration

Key Messages

- Despite growing global investments in ecosystem restoration, **seed supply for native tree species remains a major bottleneck**, particularly in the Global South where species diversity is high and natural seed sources dwindling due to land use change.
- Country-specific **availability of site-adapted tree seed for restoration can be assessed through a new methodology** which combines environmental clustering to define seed zones, Maxent species distribution models for target tree species, and data on existing seed sources.
- Application of the method to 21 native pilot species in Bangladesh, India, Indonesia, and the Philippines revealed that, on average, **only 34% of seed zones had designated seed sources**, despite the species being widely used in restoration.
- Almost all seed sources (97%) were predicted to **remain within the species' suitable habitat under future climates,** showing that informed investments in establishing seed sources can bring sustained benefits.
- The gap analysis methodology enables countries to **strategically prioritize areas for seed source development,** supporting the achievement of national restoration goals.

Introduction

The availability of appropriate tree seeds has emerged as a critical bottleneck that limits the scale and success of ecosystem restoration as a nature-based solution [1]. The national restoration targets have been estimated to require over 150 billion seeds and seedlings in India, Indonesia, Malaysia, and the Philippines combined [2]; and anywhere between 2 and 17 trillion seeds globally [3]. However, **seed production systems are reported to exist for less than 2% of the world's known tree species** [4]. The challenges of seed availability are particularly acute in human-dominated landscapes in the Global South. Quality seeds of locally preferred and suitably adapted species are crucial for restoring productive and socio-ecologically resilient landscapes that help address the underlying reasons of degradation, including multi-dimensional poverty.

Presently, it is difficult for individual restoration projects to achieve optimal seed sourcing that combines genetic diversity, site suitability and adaptability, because **most countries lack sector-wide planning tools, such as registries of seed sources and seed and seedling suppliers [5], and seed zones** to guide seed transfer.

To address these gaps, we tested and demonstrated **a spatially explicit methodology to assess the availability of tree seed sources and prioritize interventions** to enable effective forest restoration as a nature-based solution in diverse land use contexts. The proposed methodology establishes a foundation for planning native tree seed supply beyond individual restoration projects.

We demonstrate the gap analysis methodology by applying it to 21 native restoration priority species in four South and Southeast Asian countries, **Bangladesh, India, Indonesia, and the Philippines**, the combined restoration targets of which exceed 47 million hectares.

Context of tree seed systems in the study countries

The study countries, India, Bangladesh, Indonesia, and the Philippines, represent a range of environmental, social, and political contexts that affect the demand and supply of tree seed for restoration. Main governance mechanisms related to land restoration and local community participation in tree seed supply are summarized in Table 1 and are generally more advanced in Indonesia and the Philippines than in India and Bangladesh.

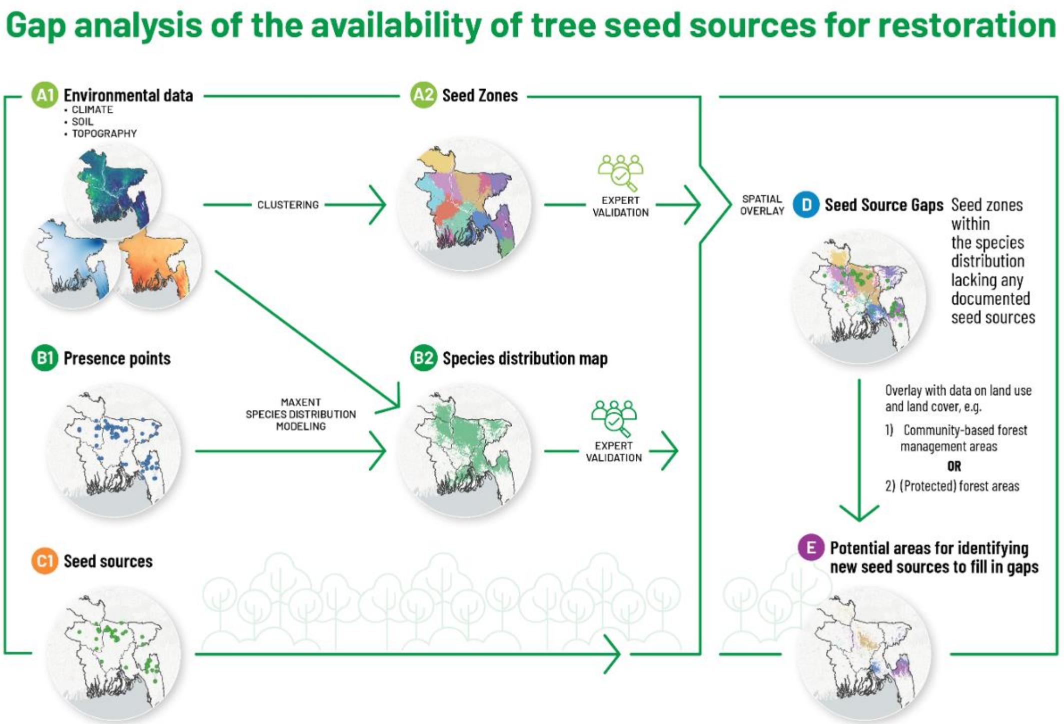

Figure 1: Overview of the methodology to assess gaps in the availability of tree seed sources. A1-A2: The country is divided into generalized seed zones based on climate and soil data and climate predictions [6]. The seed zones are then compared with species' modeled distributions (B1-B2) and existing seed sources (C1) to identify seed zones which lack seed sources for the target species (D). Once the gaps in seed sources are identified, they can be compared, for example, with forest cover maps, protected area maps or maps of community forests, to help identify potential new seed sources (E).

Table 1. Overview of governance mechanisms related to tree seed supply for restoration in the study countries.

	Bangladesh	India	Indonesia	Philippines
Land restoration goal [1]	0.75 Mha by 2030	26 Mha by 2030	14 Mha by 2030	7.1 Mha by 2028
Regulations mandating restoration	-	Yes	Yes	Yes
Regulations on tree seed quality and origin for restoration	-	-	Yes	Yes
Defined seed zones	-	-	(Yes) [2]	-
Participatory forest management	Yes	Yes	Yes	Yes
Mechanisms to register seed sources on private land	-	-	Yes	Yes
Government restoration programmes engage community organisations to supply seed or seedlings	-	-	Yes	Yes

[1] Combined from National Forestry Policies, Nationally Determined Contributions, Land Degradation Neutrality targets. Source: [7]. [2] Seed zone map exists but resembles a forest type map [8].

Table 2. Availability of known seed sources by seed zone within species' modeled ranges in study countries

Species	Conservation Status[1]	Country (target area)	Total number of seed sources	Zones within species distribution	Zones with designated seed sources	
					Number	%
Pitraj (*Aglaia chittagonga*)	VU	Bangladesh (country- wide)	36	11	7	64
Rongi-rata (*Aglaia spectabilis*)	LC		37	12	9	75
Chapalish (*Artocarpus chama*)	NE		34	8	6	75
Kanak (*Schima wallichii*)	LC		29	10	4	40
Dharmara (*Stereospermum colais*)	LC		37	5	3	60
Agarwood (*Aquilaria malaccensis*)	CR	Indonesia (Java)	25	13	1	8
Sengon (*Falcataria falcata*)	LC		26	18	5	28
Manglid (*Magnolia sumatrana*)	LC		0	19	0	0
Jabon Putih (*Neolamarckia cadamba*)	NE		3	22	0	0
Pinus (*Pinus merkusii*)	VU		24	22	3	14
Amboina pine (*Agathis dammara*)	VU	Philippines (Mindanao)	6	9	1	11
Kalingag (*Cinnamomum mercadoi*)	LC		0	8	0	0
Bagras (*Eucalyptus deglupta*)	VU		0	9	0	0
Narra (*Pterocarpus indicus*)	EN		0	8	4	50
White Lauan (*Pentacme paucinervis*)	LC		24	9	0	0
Indian rosewood (*Dalbergia latifolia*)	VU	India (Andhra Pradesh, Kerala, Karnataka, Tamil Nadu)	228	28	14	50
Indian kino (*Pterocarpus marsupium*)	NT		49	33	11	33
Teak (*Tectona grandis*)	EN		149	33	8	24
Baheda (*Terminalia bellirica*)	LC		35	33	16	48
Black myrobalan (*Terminalia chebula*)	LC		55	33	20	61
Burma ironwood (*Xylia xylocarpa*)	LC		38	33	17	51

[1]Conservation status on the IUCN Red List of Threatened Species: CR=Critically Endangered, EN=Endangered, VU=Vulnerable, NT=Near Threatened, LC=Least Concern, NA=Not Evaluated (2025).

Seed sources by seed zone and gap analysis in the study countries

The number of seed sources per species was generally heavily clustered in a few seed zones, resulting in wide gaps in the availability of native tree seed sources for all countries and almost all species (Table 2, Figure 2). Across all species, an average of **only 34% of seed zones within the species predicted distributions had designated seed sources, and 24% of the species had no seed sources at all**.

Seed sources covered the environmental range of the selected species best in Bangladesh, where 40-75% of seed zones had at least one designated seed source. The situation was the worst in Mindanao, Philippines, where only two of the five study species had any designated seed sources, followed by Java, Indonesia, where only three of five species had seed sources.

The results suggest that **known natural populations of the selected species may be sufficient to fill in identified gaps in Java and Mindanao islands.** These results can help target field surveys to determine whether population sizes are adequate to produce quality and genetically diverse seed.

While Indonesia and the Philippines have in place mechanisms to register seed sources also on private lands, they had much fewer seed sources than Bangladesh and India, where seed sources are registered only on public lands. Our results show that **community-managed forests could play an important role in filling gaps in seed source availability**, particularly in Mindanao, the Philippines, but the **reasons for the low registration of seed sources on private and communal lands must first be understood.**

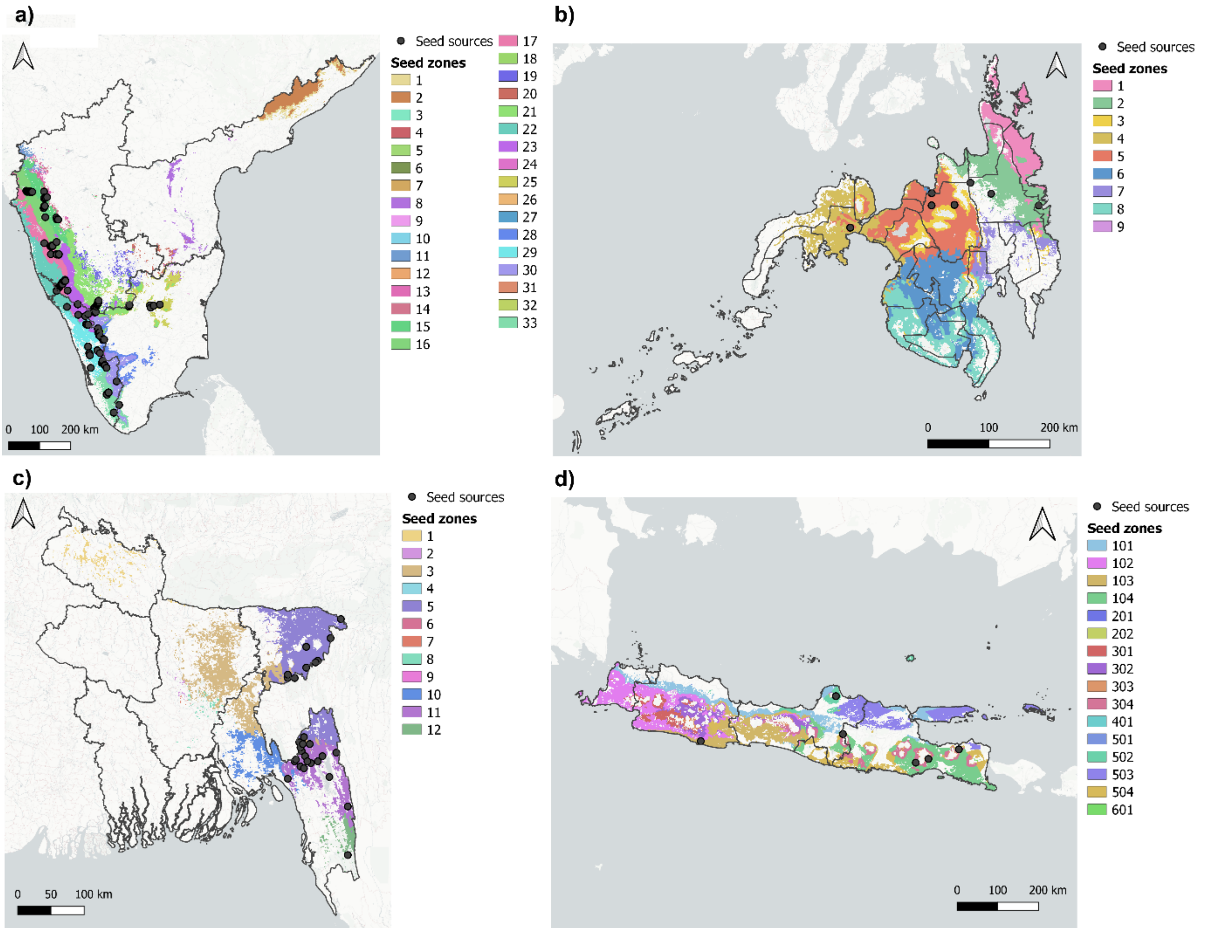

Figure 2: Visual representation of the seed source gap analysis, showing the seed sources (black dots) and seed zones within the distribution range of four of the pilot species, using one species per target region as example: (a) *Dalbergia latifolia* in the four southern states of India, (b) *Pterocarpus indicus* in Mindanao (Philippines), (c) *Schima wallichii* in Bangladesh and (d) *Falcataria falcata* in Java (Indonesia). The shown borders indicate the boundaries of the first-level administrative divisions ('states' in India, 'provinces' in Mindanao and Java, 'divisions' in Bangladesh).

Recommendations for policy and practice

Considering the fundamental role of seed availability and quality in restoration success, governments and organizations in the Global South are recommended to urgently invest to:

- Develop seed zone maps to guide seed sourcing and help identify opportunities for involving indigenous peoples and local communities in seed supply.
- Develop publicly available registries of seed sources and seed suppliers.
- Build accessible mechanisms to register seed sources on private and communal lands
- Identify and fill gaps in seed source availability, including through working with community forestry groups and establishing seed orchards.
- Develop policy and legislative frameworks that help create demand for quality seed of native species, such as regulations mandating restoration of degraded ecosystems and seed quality standards.
- Develop collaboration mechanisms such as multi-stakeholder platforms and seedling buy-back programmes.

References

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