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Editorial



Early Warning to Early Action: Closing the Last-Mile Gap in Climate Disaster Risk Management across South Asia

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ABSTRACT

Early warning systems are a central adaptation measure, and 119 countries now report a multi-hazard early warning system. Coverage, however, does not guarantee protection. This article examines the last-mile gap, defined as the failure to convert a hazard signal or forecast into protective action by the most exposed people, in South Asia. A narrative review of peer-reviewed literature and institutional reports is combined with analysis of three recent cases: the South Lhonak glacial lake outburst flood of 2023, the El Niño-affected monsoon of 2026, and the Rasuwa flash flood of 2026. The analysis finds that (i) barriers are distributed along the whole chain from detection to action; (ii) mass-movement-triggered mountain floods can reach the nearest settlements faster than any plausible detection-to-alert interval; (iii) the strongest South Asian evidence on anticipatory action comes from a single flood in Bangladesh; (iv) widely cited benefit–cost statistics for early warning are weakly sourced; and (v) indigenous and local knowledge can supply trusted intermediaries and short-notice cues if it is validated and formally integrated. Implications for loss and damage accounting in the Hindu Kush Himalaya are discussed, and a warning-to-action audit trail is proposed. Seven policy recommendations and three research priorities are presented. Data on the 2026 events are provisional.

KEYWORDS: early warning systems; last-mile gap; anticipatory action; glacial lake outburst flood; indigenous and local knowledge; loss and damage; Hindu Kush Himalaya; South Asia

INTRODUCTION

Warnings save lives only when they reach people in time, in a form that is understood, and when those people are able to act on them. Early warning systems (EWS) are therefore treated as a core adaptation measure in international disaster and climate policy. The availability of, and access to, multi-hazard early warning systems (MHEWS) is Target G of the Sendai Framework for Disaster Risk Reduction 2015–2030 (United Nations Office for Disaster Risk Reduction [UNDRR], 2015). The United Nations initiative Early Warnings for All (EW4All), launched in 2022, aims to protect every person on Earth by an early warning system by the end of 2027 (World Meteorological Organization [WMO] & UNDRR, 2025).

Progress has been measurable. A total of 119 countries (60% of all countries) now report a MHEWS, compared with 52 countries in 2015 (WMO, 2025b; WMO & UNDRR, 2025). Coverage, however, is not protection. The 2025 global status report notes that a system is comprehensive only when all four pillars function, and that fewer than one-third of countries report capabilities for risk knowledge, the foundation of all other components (WMO & UNDRR, 2025).

South Asia during 2023–2026 provides three contrasting cases. The first is the South Lhonak glacial lake outburst flood (GLOF) of October 2023 in Sikkim, India, a cascade that began far above any settlement and destroyed the Teesta III hydropower project (Sattar et al., 2025). The second is the 2026 monsoon. Seasonal forecasts of below-normal rainfall were issued months in advance, and the season closed 12.6% below the long-period average (Mukherjee, 2026; Madhyamam, 2026). The third is the Rasuwa flash flood of 26 August 2026 in Nepal, an event whose trigger lay in a remote, uninstrumented headwater and whose first impacts reached border settlements within minutes, according to compiled institutional accounts (International Centre for Integrated Mountain Development [ICIMOD], 2026).

The three cases differ in hazard type, lead time and exposed population, yet they raise a common question: under which conditions does a warning, or a forecast, become protective action for the most exposed

people? In this article, the term *last-mile gap* denotes the failure of that conversion. The term is extended to include failures upstream of the last mile, namely the failure to detect a hazard at all.

The objectives are to (i) summarise the South Asian risk landscape; (ii) assess early warning systems against the four-pillar framework; (iii) examine barriers to reach and action; (iv) review the evidence on anticipatory action and its financing; (v) examine the role of indigenous and local knowledge (ILK); and (vi) draw implications for loss and damage accounting in the Hindu Kush Himalaya (HKH) and for policy. The review is narrative and based on peer-reviewed literature and institutional reports. Data on the 2026 events are provisional and are identified as such.

The South Asian Risk Landscape

A warming region with high hydro-climatic variability

Asia warmed faster than the global average during 1991–2025, and the regional warming trend was nearly twice as strong as that of 1961–1990. The annual mean temperature in 2025 was 0.96 °C above the 1991–2020 average (WMO, 2026). Southern Asia received above-average precipitation in 2025, with exceptionally heavy monsoon rainfall. In Pakistan, monsoon flooding was associated with more than 1,000 deaths and left over 3 million people requiring assistance (WMO, 2026). All 23 monitored glaciers in High Mountain Asia (HMA) lost mass in the 2025 glaciological year, and multiple GLOFs and glacier collapses were recorded during 2025 (WMO, 2026).

Drought and El Niño: a forecast that preceded the impact

Seasonal rainfall deficit is the second pole of hydro-climatic risk. The India Meteorological Department (IMD) lowered its 2026 southwest monsoon forecast from 92% to 90% of the long-period average (LPA) in late May, citing El Niño development (Mukherjee, 2026). By 31 July, moderate El Niño conditions prevailed, and below-normal rainfall (less than 94% of LPA) was forecast for August–September (IMD, 2026). The season ended with 759.4 mm against an LPA of 868.6 mm, a deficit of 12.6%. East and Northeast India received 1,017.1 mm, the lowest seasonal total in the record that begins in 1901 (Madhyamam, 2026).

The forecast signal therefore preceded the impact by several months. Whether it triggered pre-agreed actions in the most affected districts, such as seed and input provisioning, water allocation or contingent financing, is not documented in the sources reviewed. This constitutes an evidence gap that is addressed in Section 5.

Mountain cryosphere hazards

Global glacial lake number, area and volume increased by 53%, 51% and 48%, respectively, between 1990 and 2018 (Shugar et al., 2020). A global assessment estimated that 15 million people are exposed to potential GLOF impacts, of whom about 9.3 million (62%) live in HMA. More than half of the exposed population lives in four countries: India, Pakistan, Peru and China (Taylor et al., 2023). That assessment concluded that the danger is shaped by the number of people, their proximity to lakes and their capacity to cope, and not by lake hazard alone. This finding is directly relevant to warning design, because exposure and coping capacity are the components that early warning and preparedness can change.

A regional inventory documented 697 GLOFs in HMA between 1833 and 2022, with 6,906 recorded fatalities; about 23% were recurrent outbursts from three ephemeral ice-dammed lakes (Shrestha et al., 2023). Mass movements such as avalanches, rockfalls and landslides triggered 54% of events, and intense rainfall 18% (ICIMOD, 2023). A mass-movement trigger may act within minutes and leave no precursor visible to rainfall gauges.

Cascading hazards at the infrastructure interface

The South Lhonak event illustrates the cascade structure. On 3 October 2023, about 14.7 million m³ of frozen lateral moraine collapsed into the lake and generated a wave of about 20 m. The wave breached the

moraine dam and released about 50 million m³ of water. The flood then eroded about 270 million m³ of sediment and overwhelmed hydropower installations along the Teesta River (Sattar et al., 2025). The flood triggered 45 secondary landslides, and intense rainfall over West Bengal and Bangladesh amplified the downstream impact (ICIMOD, 2025).

The Rasuwa event of 26 August 2026 shared several features with South Lhonak. According to ICIMOD's compilation, a slab of rock and glacier ice detached from the north face of Langtang Lirung shortly after 8:37 am and entered the Lhende Khola. The resulting debris flow travelled down the Bhote Koshi and Trishuli rivers. No heavy rainfall was recorded, and the trigger was reported to lie on the Nepali side of the border, although early reports had placed the source in Tibet (ICIMOD, 2026). The Nepal Society for Earthquake Technology (NSET) listed an ice–rock avalanche with temporary blockage and release in the upper Lhende catchment as the leading technical hypothesis, with other mechanisms, including glacial lake outburst, still under investigation (NSET, 2026). A different mechanism had operated in the same valley in July 2025, when a supraglacial lake on the Purepu Glacier in Tibet drained (The Himalayan Times, 2025).

NSET reported 14 affected energy projects (combined footprint 748 MW) and 11,793 affected households. Casualty counts varied widely between sources; its 29 August report listed provisional figures of 675 deaths and 2,498 people missing, pending reconciliation (NSET, 2026).

The common features of the two cascades are an initiation in unmonitored high-altitude terrain, amplification through the entrainment of sediment, and severe damage to hydropower and transport infrastructure far downstream. Each feature has a direct consequence for early warning, which is examined in Sections 3 and 4.

State of Early Warning Systems

Architecture and coverage

EW4All organises early warning into four pillars: disaster risk knowledge; detection, observation, monitoring, analysis and forecasting; warning dissemination and communication; and preparedness and response capabilities. The initiative is spearheaded by WMO, UNDRR, the International Telecommunication Union (ITU) and the International Federation of Red Cross and Red Crescent Societies (IFRC) (WMO, 2025b). Table 1 lists selected status indicators from the 2025 reporting cycle.

Table 1. Pillars of Early Warnings for All and selected status indicators, 2025

Pillar	Lead partner	Selected indicator
1. Disaster risk knowledge	UNDRR	Fewer than one-third of countries report risk-knowledge capabilities; improvement of 16% since 2022 (WMO & UNDRR, 2025)
2. Detection, observation, monitoring and forecasting	WMO	56% of WMO Members use satellite data for at least one hazard; 20% do so for all priority hazards (WMO, 2025b)
3. Warning dissemination and communication	ITU	Adoption of the Common Alerting Protocol (CAP) has surged (WMO, 2025a)
4. Preparedness and response capabilities	IFRC	Evacuations increased markedly in the last year; pre-disaster anticipatory action is gaining momentum (WMO & UNDRR, 2025)

Coverage differs by region. Asia-Pacific reports the highest regional coverage of MHEWS (72%) and small island developing States the lowest (43%), and comprehensiveness scores have risen by an average of 45% across regions since 2015. Disaster mortality is nearly six times lower in countries with more comprehensive MHEWS capabilities

(WMO & UNDRR, 2025). These are cross-country associations. They are not causal estimates, and they are confounded by income, governance and hazard profile.

MONITORING, FORECASTING AND IMPACT-BASED WARNING

Under Pillar 2, the launch of the WMO Information System 2.0 (WIS2) in 2025 reduced the equipment barrier to data exchange for small national meteorological and hydrological services. More than 150 centres in the WMO Integrated Processing and Prediction System (WIPPS) supply forecast products regardless of national modelling capacity, and the Severe Weather Forecasting Programme supports 85 Members (WMO, 2025b). The number of surface stations sharing data has grown by about one-fifth since 2019 (WMO, 2025b).

The operational shift in service delivery is from forecasting what the weather will be to forecasting what the weather will do. The WMO guidelines on impact-based forecast and warning services (IBFWS) describe the milestones of this shift (WMO, 2015). The second part of the guidelines notes that IBFWS implementation is still in its early stages, especially for the most vulnerable communities (WMO, 2021). Impact-based products depend on exposure and vulnerability data. The low reported coverage of risk knowledge (Table 1) therefore, constrains the quality of Pillar 2 outputs, and the pillars cannot be improved independently of each other.

Tropical cyclone warning shows what sustained investment across all four pillars can achieve. Ahead of Cyclone Fani (May 2019), Odisha evacuated about 1.2 million people in 24 hours (Al Jazeera, 2019). UNDRR cited the near-pinpoint accuracy of IMD warnings, which allowed a well-targeted evacuation (Red Cross Red Crescent Climate Centre, 2019). The state's approach built on lessons from the 1999 super cyclone, which caused more than 10,000 deaths (Gulf News, 2019). In Bangladesh, the Cyclone Preparedness Programme has more than 76,000 volunteers, half of them women (World Bank, n.d.). Mountain cryosphere hazards are at the opposite end of the maturity spectrum. ICIMOD scientists reported in 2025 that only two lakes in Nepal, Imja and Tsho Rolpa, had early warning systems (The Himalayan Times, 2025).

EVIDENCE ON EFFECTIVENESS AND THE LIMITS OF HEADLINE STATISTICS

The Global Commission on Adaptation (GCA) reported that 24 hours of warning can reduce ensuing damage by 30%, and that an investment of US$800 million in early warning in developing countries could avoid losses of US$3–16 billion per year (GCA, 2019). These figures are repeated widely, including in EW4All communication materials (IFRC, 2022).

A tracing exercise found that the GCA report is a synthesis and not the original source of these statistics (Stephens, 2023). The 30% figure appears to derive from a 1970 flood-warning evaluation for a single river basin in the United States, compiled in a 2012 World Bank study (Hallegatte, 2012; Stephens, 2023). The claim of a tenfold return lacks specific evidence for disaster risk management, because most underlying studies address hydrometeorological services across weather-sensitive sectors. The World Bank study estimated a saving of about 23,000 lives per year and benefit–cost ratios of about 1 to 5.5 for disaster risk management, and it assumed parallel investment such as cyclone shelters (Hallegatte, 2012; Stephens, 2023). The US$800 million represented an annual cost over five years for 80 countries (Stephens, 2023).

The implication is not that early warning is ineffective. The implication is that the global statistics should be cited with their origin and assumptions, and that effectiveness in a specific hazard and context requires local evidence. In this article, the GCA figures are reported as indicative only.

THE LAST-MILE GAP: BARRIERS FROM DETECTION TO ACTION

The last mile is conventionally the final segment of the dissemination chain. Evidence from South Asia indicates that failure points are

distributed along the whole chain, from detection to protective action. Table 2 summarises eight barriers. Much of the 2026 evidence comes from rapid post-event compilations, and formal after-action reviews are needed before causal claims about warning performance can be made.

Table 2. Barriers between hazard onset and protective action, with South Asian evidence

Barrier	Evidence
Detection gap	Rasuwa 2026: trigger above 5,000 m on the Nepali side; no heavy rainfall, so rainfall-based flood warning was not triggered; downstream alerts followed the inundation of border settlements (ICIMOD, 2026)
Lead time	The flood reached the nearest settlements faster than a plausible detection-to-alert interval; timings differ among sources by tens of minutes (ICIMOD, 2026)
Transboundary data	Upstream data, imagery and a joint warning protocol with China are listed among priority coordination needs (NSET, 2026)
Communication infrastructure	Mobile and backhaul disruption obstructed warning, search and tracing (NSET, 2026)
Language and transient populations	Many victims were pilgrims and hydropower workers who may not have been able to read an alert issued in Nepali (ICIMOD, 2026); 157 foreign nationals and 133 people at hydropower projects were among the provisionally listed missing (NSET, 2026)
Digital and gender divide	Women in South Asia were 32% less likely than men to use mobile internet in 2024 (GSMA, 2025)
Trust and knowledge conflict	Official evacuation advice can clash with locally trusted authorities (Mallapaty, 2012; Mercer et al., 2010)
Risk knowledge and governance	Fewer than one-third of countries report risk-knowledge capabilities (WMO & UNDRR, 2025); a 24-hour basin cell, formal all-clear criteria and impact-based forecasts remain listed as coordination needs for the Trishuli corridor (NSET, 2026)

DETECTION AND LEAD TIME

The first two barriers are physical before they are institutional. Rainfall-based and river-gauge-based flood warning systems monitor conditions that precede or accompany a flood caused by water. A flood released by a mass movement in a dry period does not cross those thresholds until it arrives.

According to ICIMOD's compilation, the Rasuwa flood was not preceded by heavy rainfall, and the nearest settlements were reached faster than any plausible detection time. The same compilation reports that downstream locations such as Malekhu were reached more than two hours after the first SMS alerts were issued (ICIMOD, 2026). The value of a warning therefore differs sharply along the flow path: it is measured in minutes near the source and in hours at distance.

For the settlements closest to the source, technology cannot supply the missing lead time. Protection must come from hazard-informed siting of settlements and infrastructure, from local recognition of environmental cues, and from source detection that protects the corridor further downstream. ICIMOD notes that glacial lakes can in principle be inventoried and monitored, whereas unstable rock faces are far more difficult to track (ICIMOD, 2026). Warning architecture built around lake inventories therefore does not transfer directly to mass-movement hazards.

REACH, LANGUAGE AND INCLUSION

India's CAP-based integrated alert system (SACHET) is connected to all 36 states and union territories and to major mobile operators. It delivers multilingual alerts through sirens, broadcast media, display boards and mobile channels, and cell broadcast was still under testing at the time of the cited description (UNDRR, n.d.). A nationwide test was conducted on 2 May 2026 (ETV Bharat, 2026). Cell broadcast sends a message to

all mobile phones in an area at once, instead of individually (News on AIR, 2025), and it does not require recipients to use a specific app.

The digital and gender divide limits channels that rely on smartphones. In low- and middle-income countries, entry-level smartphones cost women an average of 24% of monthly income, twice the share for men (GSMA, 2025). Intermediaries who are trusted and physically present can compensate. In Bangladesh, female volunteers of the Cyclone Preparedness Programme reportedly persuade women who are reluctant to use cyclone shelters because of prejudice or misconceptions (United Nations Development Programme [UNDP], 2019).

Transient populations are a separate problem. The Rasuwa–Trishuli corridor combines pilgrim traffic, cross-border trade and hydropower construction, and the NSET tabulation of missing persons includes foreign nationals and workers at hydropower projects (NSET, 2026). People who are not registered with a local government cannot be warned by a ward-level system, and people who do not read the language of the alert cannot act on it.

Trust, comprehension and governance

Warnings are interpreted within existing systems of belief and authority. Scientific warning and local knowledge may conflict. In the best-known illustration, official evacuation orders before the 2010 Merapi eruption clashed with the advice of the volcano's spiritual gatekeeper, who died in the eruption (Mallapaty, 2012). Mercer et al. (2010) argue that integration of the two knowledge systems requires a participatory framework, because neither system is sufficient alone.

Governance determines whether detection, warning and response are connected. Table 1 shows that risk knowledge, the first pillar, is the weakest in global reporting. At the corridor level, the coordination matrix of the Rasuwa response lists a 24-hour basin cell, formal all-clear criteria and impact-based forecasts among the next requests for the hydrological service (NSET, 2026). These are institutional gaps that remain after a major event, and they indicate that the conversion of a hazard signal into a decision is not yet routinised.

Anticipatory Action and Financing

Concept and design

Anticipatory action converts a forecast into pre-agreed action before a hazard produces its impact. Forecast-based financing, an early formalisation, matches threshold forecast probabilities with appropriate actions, releases funding when a threshold forecast is issued, and develops standard operating procedures that carry the mandate to act (Coughlan de Perez et al., 2015). The central design problem is that it is unclear which levels of forecast probability and magnitude justify action. The Red Cross Red Crescent network has pursued the approach since 2014 (IFRC, 2022). Because forecast skill and available actions vary by hazard and location, triggers require local calibration.

Evidence from the Bangladesh floods of 2020

The most rigorous South Asian evidence concerns the 2020 monsoon floods in Bangladesh. The World Food Programme (WFP) sent BDT 4,500 (about US$53) through mobile money to households that were forecast to experience extreme flooding, on the basis of an impact-based forecast (Pople et al., 2021). The transfer reached households about 100 days earlier than previous WFP interventions in the same context. The evaluation compared recipient households with otherwise comparable non-recipients and reported the following results (Pople et al., 2021):
Recipient households were 36% less likely to go a day without eating.

Recipient households were more likely to evacuate (12%) and to evacuate livestock (17%), and they were better able to avoid costly borrowing.

Effects persisted three months later, and earlier transfers were more effective. Acting one day earlier near the flood peak improved welfare.

These results indicate that anticipatory transfers widen the set of actions available to households during the critical interval. The evidence has limits. It concerns a river flood with a lead time of several days and a specific delivery channel, and it comes from a single event. Evaluations of this type remain scarce in the humanitarian sector (Pople et al., 2021;

Weingärtner et al., 2020), and transferability to flash floods, drought or mountain hazards cannot be assumed.

SLOW-ONSET AND MOUNTAIN HAZARDS

For drought, forecast lead times of months permit a graded protocol. IMD forecast information on the 2026 monsoon was available from April (Mukherjee, 2026; IMD, 2026). A forecast-based design would link low-regret actions, such as input and seed provisioning, water-allocation planning and advisories, to lower probability thresholds. Higher-cost actions, such as cash transfers or insurance pay-outs, would be linked to higher thresholds or to confirmed deficits in the early season. These are design options derived from the forecast-based financing framework. They are not documented as implemented in the districts affected in 2026, and an after-season evaluation would be needed to establish what was done.

For cascading mountain hazards, forecasting at event lead times is not feasible, and anticipatory action operates on three other timescales:

- **Years to months.** Risk-informed siting of settlements and infrastructure, marked escape routes, registration of workers and visitors, and regular drills.
- **Weeks.** Precursor signals. ICIMOD's compilation cites preliminary satellite-radar analyses that suggest slope displacement of up to 30 cm in the three to four weeks before the Langtang Lirung failure (ICIMOD, 2026). These analyses are unpublished. If they are confirmed, displacement thresholds could trigger restrictions on access to river-edge sites. The false-alarm burden would be high, because many slopes that appear unstable never fail (ICIMOD, 2026).
- **Minutes.** Automated detection linked to sirens. ICIMOD's compilation describes a sensor-and-siren system in Bhutan that sounds sirens automatically within 15 minutes of detection (ICIMOD, 2026). Such systems protect the corridor beyond the first settlements, not the settlements adjacent to the source.

FINANCING

Anticipatory action has been funded mainly by humanitarian donors (IFRC, 2022). The Fund for responding to Loss and Damage (FRLD) allocated US$250 million to its start-up phase, the Barbados Implementation Modalities, for 2025 and 2026 (FRLD, 2025), and funding requests of up to about US$3 billion were reported (Eco-Business, 2026). The COP30 decision asks the FRLD Board to consider rapid disbursement modalities in its long-term operating model (United Nations Framework Convention on Climate Change [UNFCCC], 2025). Rapid disbursement is a precondition for trigger-based finance. If such modalities are adopted, they could in principle finance forecast-triggered protocols, but this is an opportunity and not a documented plan.

The financing case also depends on evidence. As shown in Section 3.3, widely cited benefit–cost statistics are weakly sourced, and local evaluations of cost and effect, in the style of the Bangladesh study, would provide a firmer basis.

COMMUNITY-BASED AND INDIGENOUS AND LOCAL KNOWLEDGE APPROACHES IN CASCADING-HAZARD SETTINGS

CONCEPTUAL BASIS

People-centred early warning places the exposed community at the centre of system design. Integration of local and scientific knowledge is recommended at all stages of EWS design and is expected to narrow the gap between the information that systems produce and the information that communities can use (Bucherie et al., 2022). Mercer et al. (2010) proposed a participatory framework for integrating indigenous and scientific knowledge. Hiwasaki et al. (2014) developed a process, tested in Indonesia, the Philippines and Timor-Leste, in which local knowledge is observed, documented, validated and categorised: knowledge that can be validated is integrated with science, and knowledge that cannot be scientifically explained is safeguarded and valorised. A review of the

integration literature organised the evidence by approach, by pillar, and by outcomes and challenges (Hermans et al., 2022).

Evidence from South Asia

In the Chitwan District of Nepal, Practical Action improved community flood forecasting by installing rainfall gauges and training local messengers, known as *katuwals*, to spread information on forthcoming floods. Before this, residents relied on telephone calls from relatives upstream (Mallapaty, 2012). The case shows that informal upstream–downstream networks existed before formal systems and that a formal system can be built on them. In Bangladesh, the Cyclone Preparedness Programme volunteer network exceeds 76,000 members, half of whom are women (World Bank, n.d.). During Cyclone Bulbul in 2019, trained volunteers supported by a UNDP programme disseminated early warning messages and moved people to shelters. A third of the volunteers in that programme were women, who were reported to play a significant role in mobilising women and children (UNDP, 2019).

Application to Cascading Mountain Hazards

The evidence base for ILK in cascading mountain hazards is thinner than for cyclones and floods. Three observations from the sources reviewed are relevant.

First, local sources improve the hazard record itself. The HMA GLOF inventory attributes 906 fatalities to 24 events, a figure about three times higher than a previous regional assessment, and its authors stress the need for interdisciplinary approaches that include local knowledge (Shrestha et al., 2023; ICIMOD, 2023).

Second, local cues may provide minutes of warning where no instrument exists. ICIMOD's public guidance proposes community triggers that are agreed in advance, such as an audible roar upstream or a sudden change in the river, with immediate movement to high ground (ICIMOD, 2026). The value of such a trigger depends on prior agreement, on the availability of an escape route, and on the distance of the settlement from the source. The sources reviewed do not report an evaluation of this approach in the Himalaya, and this is a research gap.

Third, local historical memory can inform siting. ICIMOD's compilation notes that the confluence at Rasuwagadhi, where debris flows slow and deposit their heaviest load, coincided with the customs yard, dry port and hydropower works (ICIMOD, 2026). The sources reviewed do not document the use of local flood memory in this corridor.

Limits and Design Principles

Local knowledge has limits. Traditional knowledge does not always reduce vulnerability, and it may not adapt quickly to changing social and climatic conditions (Mallapaty, 2012). Warming is also producing hazards without close historical analogues. A supraglacial lake on the Purepu Glacier first appeared as a small pond in December 2024, grew substantially by June 2025, and drained in July 2025 (The Himalayan Times, 2025). Knowledge that is based on historical experience may not recognise a hazard that forms within months.

The evidence reviewed supports five design principles for ILK-based components:

- **Validation.** Local observations should be inventoried and validated jointly by communities and scientists, following the process of Hiwasaki et al. (2014).
- **Formal roles.** Local messengers and monitors should hold defined roles within the official system, as in Nepal and Bangladesh.
- **Gender balance.** Volunteer corps should include women, who can reach households and persuade reluctant members to evacuate (UNDP, 2019).
- **Redundancy.** Community triggers should be paired with sirens and other channels that do not depend on mobile networks.
- **Two-way flow.** Community observations should be fed back into official monitoring, and not only used to distribute official messages.

Implications for Loss and Damage Accounting in the Hindu Kush Himalaya

The performance of an early warning system is measured in avoided and residual loss, and both depend on loss and damage (L&D) accounting that records what was lost, by whom, and which warnings and protective actions preceded the loss. In the Hindu Kush Himalaya, record quality is a limiting factor. The HMA GLOF inventory shows that evaluation of local sources changes fatality estimates substantially (Shrestha et al., 2023), and the Rasuwa response shows the same problem in real time: counts diverged between sources, and a single casualty and missing-person registry is listed among NSET's coordination requests (NSET, 2026). As the FRLD moves from design to disbursement (FRLD, 2025; UNFCCC, 2025), the evidence standard for funding requests will raise the value of auditable loss records.

A *warning-to-action audit trail* is proposed here as a minimum record for each hazard event. It would contain five elements:

the time of hazard onset and the time of detection;

the time of alert issuance, together with the language and channel used;

the estimated population reached and the protective actions taken;

losses by category and household; and the residual risk remaining after the event.

These fields convert warning performance into auditable data. They also allow verification practice from greenhouse gas accounting to be adapted, in particular the principles of relevance, completeness, consistency, accuracy and transparency that govern quantification and reporting under ISO 14064-1 (International Organization for Standardization [ISO], 2018). The standard addresses greenhouse gas inventories, and its use here is an analogy for verification design and not a claim of direct applicability.

An ongoing project supported by the Asia-Pacific Network for Global Change Research (APN; reference CBA2025-07MY-Sengupta, October 2025–September 2027) builds capacity for risk accounting and auditing in climate-sensitive agrarian socio-ecologies of the Hindu Kush Himalaya. The South Asian Forum for Environment is the grantee, with the IIT Madras–Progyan Foundation for Research and Innovation (PFRI, the author's institution), Social Transformation Nepal and the Ugyen Wangchuck Institute for Conservation and Environmental Research (Bhutan) as consortium partners. The project operates in nine pilot villages in India, Nepal and Bhutan (three each) and targets 7,000 farmers. A mobile application under development is intended to collect geotagged farmer hazard reports. Such records are a candidate data source for the audit trail if validation steps are defined. Extending the application to record whether a warning was received, in which language and what action followed is proposed here; it is not a described feature of the project.

Policy and Research Recommendations

The recommendations follow from the evidence reviewed. They are addressed to national disaster management authorities, hydrometeorological services, development partners and research institutions in South Asia.

Measure action, not issuance. Sendai Target G reporting should add indicators of reach, comprehension, protective action and time-to-safety, because the presence of a system and its association with lower mortality (WMO & UNDRR, 2025) do not show whether warned people were able to act.

Rank sources above infrastructure. Unstable slopes and glacial lakes above hydropower projects, roads and towns should be ranked by hazard and exposure, multi-hazard assessment should precede project approval in glaciated catchments, and instrumentation should go first to the highest-ranked sites (ICIMOD, 2026; Sattar et al., 2025).

Make transboundary protocols operational. Source and receiving countries should agree on real-time upstream data exchange, joint investigation and joint warning protocols (ICIMOD, 2023; NSET, 2026).

Build redundant and inclusive dissemination. Cell broadcast, sirens that do not depend on mobile networks and trained volunteers should be combined (UNDRR, n.d.; News on AIR, 2025; UNDP, 2019). Alerts should be multilingual, transient workers and visitors should be registered, and channel design should account for the gender gap in mobile internet use (GSMA, 2025).

Pre-agree actions and financing. Forecast-triggered protocols with explicit thresholds and low-regret first actions should be developed for river floods and seasonal drought (Coughlan de Perez et al., 2015; Pople et al., 2021), with rapid FRLD disbursement modalities to finance them (UNFCCC, 2025) and an evaluation of each activation.

Co-produce and validate local knowledge. Communities and scientists should jointly inventory, validate and integrate local observations, with formal roles for local messengers (Hiwasaki et al., 2014; Hermans et al., 2022).

Apply evidence discipline. Effectiveness statistics should be cited with their original source and assumptions (Stephens, 2023), after-action reviews should publish detection, alert and action times, and the warning-to-action audit trail (Section 7) should be adopted.

Three research priorities emerge:

- **Precursor signals for rock–ice avalanches.** Slope-displacement monitoring should be tested against failure and non-failure cases, so that preliminary observations of pre-failure movement (ICIMOD, 2026) can be converted into validated trigger thresholds.
- **Trigger calibration and cost–benefit by hazard and context.** This includes drought in eastern and north-eastern India, where the 2026 monsoon deficit was greatest (Madhyamam, 2026).
- **Comparative evaluation of last-mile interventions.** Cell broadcast, volunteer networks and community triggers should be evaluated in Himalayan settings with outcome measures of protective action.

CONCLUSION

Early warning in South Asia has reached high maturity for some hazards and has barely begun for others. Cyclone warning shows that sustained investment across all four pillars can convert forecasts into evacuation at scale. The 2026 monsoon shows that a forecast can be accurate months ahead while the question of action remains open. The Sikkim and Rasuwa cascades show that, for mass-movement-triggered floods, the first settlements may lie within minutes of the source, so that no dissemination technology can close the gap on its own.

Closing the last-mile gap therefore requires three shifts: from issuing warnings to measuring protective action; from hazard-specific systems to source-to-community chains that include detection, transboundary data exchange and inclusive dissemination; and from post-event response to pre-agreed action supported by rapid finance. Indigenous and local knowledge can supply short-notice cues and trusted intermediaries, provided that it is validated and formally integrated.

The evidence base remains thin in several places, including the performance of the 2026 warning chains, and the 2026 event data used here are provisional. The first priority for the next cycle is evaluation, because decisions on investment, regulation and loss and damage finance depend on evidence of what warned people were able to do.

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Biodiversity Finance and the Kunming-Montreal Global Biodiversity Framework: Can India Mobilise Resources for Ecosystems and Communities?

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STANDFIRST: India has a costed biodiversity plan with projected annual requirements of ₹81,664.88 crore, more than a decade of biodiversity finance-planning experience covering 116 schemes across 24 Union ministries, and 276,653 constituted Biodiversity Management Committees. These institutional assets provide an important foundation, but their effectiveness depends on securing the necessary finance, demonstrating ecological improvements and ensuring equitable benefits for communities. As resource mobilisation is debated at CBD COP17 in Yerevan, India must address these domestic questions alongside the international financing shortfall.

THE CENTRAL PROBLEM

The Kunming–Montreal Global Biodiversity Framework (GBF), adopted in December 2022, contains 23 targets for 2030. Under Target 19, countries are expected collectively to mobilise at least USD 200 billion annually for biodiversity by 2030, including international financial flows to developing countries of at least USD 20 billion each year by 2025 and USD 30 billion by 2030. Target 18 requires the identification and reform of environmentally damaging incentives, while Target 14 calls for biodiversity considerations to be integrated into fiscal, economic and development decisions (Convention on Biological Diversity [CBD], 2022). Resource mobilisation is therefore not confined to establishing conservation funds: it also concerns the ways in which governments and businesses raise, allocate and spend money.

The first global assessment of implementation, *State of Biodiversity Action*, was launched in October 2026. Nearly 90% of parties had established national biodiversity targets, but fewer than half of the targets assessed were on course for achievement (CBD, 2026a). The international-finance milestone for 2025 has also been missed. For India, the immediate test is whether established financing arrangements can produce verifiable conservation results and tangible benefits for the people who manage biological resources.

GLOBAL BIODIVERSITY FINANCE: COMMITMENTS AND DELIVERY

The Organisation for Economic Co-operation and Development (OECD) estimates that global biodiversity finance amounted to USD 74.9–92.4 billion annually during 2023–2025, considerably below the USD 200 billion envisaged for 2030. Within these estimates, domestic public expenditure contributed approximately USD 46.0–63.5 billion, international public resources about USD 16.1 billion, and private finance around USD 12.9 billion (OECD, 2026). International public flows require particular attention. Based on national submissions, the CBD's global review recorded USD 17.7 billion cumulatively for 2020–2023, equivalent to approximately USD 4.4 billion annually among reporting countries. The OECD figure is substantially higher, although the two series differ in their reporting populations, reference periods and accounting methods (CBD, 2026a; Chandrasekhar, 2026). The discrepancy demonstrates the need for comparable reporting as well as increased finance.

Dedicated international funds have yet to close the financing deficit. Pledges to the Global Biodiversity Framework Fund (GBFF), administered through the Global Environment Facility, reached USD 387.2 million from 11 countries and Quebec by 30 June 2026 (Chandrasekhar, 2026). Commitments must be distinguished from contributions received and finance ultimately disbursed to projects. An even sharper contrast between potential and actual receipts is evident in the Cali Fund, which was created to channel benefit-sharing contributions from businesses using digital sequence information (DSI) derived from genetic resources. Its own COP17 information page continued to display USD 6,000 from two contributors, whereas reporting on 20–22 October 2026 identified USD 7,085 received and USD 10,656 pledged following a third corporate contribution (Agence France-Presse, 2026; Ratcliffe, 2026).

The Cali Fund's financial potential is nonetheless substantial. Indicative contribution rates are 1% of profits or 0.1% of revenue for large businesses in designated sectors. Makowska-Curran (2026) estimated annual receipts of USD 929 million under a plausible voluntary-participation scenario and up to USD 3.6 billion if all 21,690 eligible enterprises contributed. These projections do not represent money already collected. Questions concerning the voluntary character of contributions, governance and allocation remain under negotiation; more than 70 developing countries and civil society organisations have challenged aspects of the proposed arrangements (CBD Alliance, 2026). At least half of the Fund's proceeds are designated for Indigenous Peoples and local communities, although the practical arrangements for reaching eligible beneficiaries still require attention (Cali Fund, 2026).

For India, these developments establish two complementary priorities. International finance must increase, and developed countries must fulfil their commitments under Target 19. India has advocated a dedicated financing mechanism for developing countries since COP15 (Ministry of Environment, Forest and Climate Change [MoEFCC], 2022). At the same time, the limited scale and uncertain timing of international disbursements make domestic budgets, reform of existing expenditure and carefully regulated private investment indispensable to implementation.

INDIA'S COSTED BIODIVERSITY PLAN AND FINANCING REQUIREMENTS

India presented the 2024–2030 update of its National Biodiversity Strategy and Action Plan (NBSAP) on 30 October 2024 during CBD COP16 in Cali. Its 23 national targets are accompanied by an estimated average annual requirement of ₹81,664.88 crore (approximately ₹816.65 billion) for 2024–25 to 2029–30. This costing covers activities distributed across 23 Union ministries and departments; it is not an allocation of newly approved funding. The NBSAP also reports average annual biodiversity-attributable expenditure of ₹32,207.13 crore during 2017–18 to 2021–22, based on expenditure across 21 ministries and two departments (MoEFCC & National Biodiversity Authority [NBA], 2024; Ghanekar, 2024). Independent assessments have also questioned the extent of participation by stakeholders beyond government departments and scientific institutions in preparing the plan (Sirur, 2024).

The historical expenditure estimate and the projected NBSAP requirement cover different periods and use different accounting methods. Subtracting one from the other would therefore misrepresent India's current financing deficit. An updated assessment must establish which planned activities already have budgetary allocations, how much has been released and spent, and which requirements remain unfunded.

Since 2015, India has participated in the Biodiversity Finance Initiative (BIOFIN) of the United Nations Development Programme, which mapped 116 biodiversity-relevant schemes administered by 24 Union ministries and 29 departments. For 2017–18 to 2021–22, BIOFIN estimated average annual public expenditure on biodiversity at approximately USD 10 billion

against an estimated requirement of USD 16.5 billion. This represented a financing shortfall of approximately USD 6.5 billion annually during the assessment period (BIOFIN India, n.d.). India's Biodiversity Finance Plan identified four priorities: integrating biodiversity into existing government programmes, corporate social responsibility (CSR), financial technology, and access and benefit sharing (ABS). In 2025, UNDP also supported a new GBF-aligned finance plan incorporating gender considerations.

These assessments provide a financial starting point, but implementation depends on identifying responsibilities and results across departments. Expenditure relevant to biodiversity is distributed among agriculture, fisheries, water resources, rural development and infrastructure, in addition to the environment ministry. Its ₹3,759-crore provision for 2026–27 consequently cannot be treated as India's national biodiversity budget (PRS Legislative Research, 2026). Departmental accounting must establish how these expenditures contribute to the NBSAP's targets.

REFORMING EXISTING PUBLIC EXPENDITURE

The effectiveness of additional biodiversity finance depends partly on how India manages the public expenditure already committed to agriculture, intergovernmental transfers and compensatory afforestation.

Harmful incentives. Agricultural policy illustrates how public expenditure can work against conservation objectives. Regulated nitrogen-fertiliser prices may promote excessive application, while procurement and support-price policies favouring rice and wheat can discourage crop diversity. An analysis by the Indian Council for Research on International Economic Relations (ICRIER), featured in BIOFIN's work, identifies these effects and proposes pilot reforms supporting community seed banks, integrated pest management and natural farming (BIOFIN India, n.d.).

Reforming these incentives, however, is not straightforward. Fertiliser subsidies and agricultural procurement policies also support farm incomes and national food security. Their abrupt withdrawal could impose substantial economic costs on small and marginal farmers. The challenge is to redesign public support so that agricultural productivity and livelihood security are maintained without encouraging practices that damage biodiversity. This approach is consistent with Target 18, which calls for identifying and reforming environmentally harmful incentives, including a global reduction of at least USD 500 billion annually by 2030 (CBD, 2022). In India, sector-wise assessments should inform regionally appropriate reforms, with their economic and ecological effects evaluated before wider implementation.

Ecological fiscal transfers. India's fiscal-sharing arrangements already recognise the environmental value of forests. The Fourteenth Finance Commission assigned a weight of 7.5% to forest cover; the Fifteenth increased the weight of the forest-and-ecology criterion to 10%. A study by Busch et al. (2020) described the arrangement as the world's largest ecological fiscal transfer and estimated the annual value of its forest-related component at USD 7.4 billion under the arrangements studied. The Sixteenth Finance Commission has retained a 10% forest criterion for 2026–31, while distinguishing very dense, moderately dense and open forest cover. Its calculation assigns 80% of the score to existing weighted forest area and 20% to changes between 2015 and 2023 (Sixteenth Finance Commission, 2025).

Incorporating forest change into the formula is significant, but the transfer remains part of unconditional tax devolution rather than a grant payable against specific conservation outcomes. Canopy-based indicators also provide limited information about species composition, habitat quality or

community stewardship. Busch et al. (2020) found that, following the earlier reform, forestry budgets across 25 states increased by approximately 19%, while total state budgets rose by 42%. Forestry accounted for 0.99% of state expenditure before the reform and 0.83% afterwards. States benefiting more from the forest criterion did not raise forestry expenditure proportionately. The evidence favours complementary, outcome-linked grants and more transparent monitoring of forest condition rather than treating formula-based transfers as sufficient incentives on their own.

Compensatory afforestation. The Compensatory Afforestation Fund Management and Planning Authority (CAMPA) oversees one of India's largest earmarked sources of conservation-related finance. For 2019–20 to 2023–24, approved state annual plans amounted to ₹38,516 crore. Of this, ₹29,311 crore was released to forest departments and ₹26,001 crore was reported as utilised, representing 67.5% of the approved sum. The Central Empowered Committee also recorded compensatory planting across 178,261 hectares against a target of 209,297 hectares, or approximately 85% (Economic Times, 2025; Business Standard, 2025). A separate government account reports plantation activity over 3.20 lakh hectares during 2020–21 to 2024–25; the two series overlap and cannot be added together (MoEFCC, 2026a).

The figures establish incomplete utilisation, but do not establish how much ecological value compensatory activities restored following habitat diversion. A species-rich forest, wetland or other established ecosystem may not be replaceable by trees elsewhere, particularly when the original site sustains distinctive biodiversity, hydrological functions or customary resource uses. CAMPA assessment should therefore document the condition of habitats affected by diversion, the suitability of replacement sites, native species composition, plantation survival, regeneration, ecological change and the treatment of community rights. Independent field verification is essential if restoration claims are to extend beyond financial and area-based indicators.

Green India Mission. The Comptroller and Auditor General's (CAG) 2026 performance audit, covering 2015–16 to 2024–25, found that the mission received ₹1,149.14 crore over ten years, only 47.88% of the ₹2,400-crore funding provision examined. Independent spatial assessment found little or no improvement in nearly 70% of the locations assessed, alongside weaknesses in coordination and the functioning of implementation bodies (CAG, 2026). The Green India Mission is distinct from CAMPA, so its findings cannot be assumed to describe CAMPA's performance. Nevertheless, the audit demonstrates the material consequences of inadequate funding and coordination for restoration programmes.

PAYMENTS FOR ECOSYSTEM SERVICES, GREEN CREDITS AND PRIVATE FINANCE

Beyond conventional public expenditure, India has developed instruments that compensate resource managers and encourage private participation in conservation. Payments for ecosystem services (PES) compensate resource managers for maintaining ecological benefits, including water regulation, habitat protection and carbon storage. Meghalaya offers one of India's most prominent examples. According to the state's 2025–26 budget speech, GREEN Meghalaya supported approximately 3,300 individuals and communities conserving 54,000 hectares. Under the expanded GREEN Meghalaya+ programme, the basic incentive was increased to ₹10,000 per hectare, with higher payments for certain categories, and ₹100 crore was proposed for 2025–26 (Government of Meghalaya, 2025). Under the PES arrangements examined, participating landholders made a 30-year commitment to conserve their forests. Research found uneven participation, concerns about the contract period and differences in how participants understood their obligations (Bodetti, 2025).

The programme must also demonstrate *additionality*: whether its payments prevent forest degradation or clearance that would have occurred without financial incentives. Inclusion Economics India Centre is investigating this question, although no impact findings were available in the reviewed publications. Similarly, a separate J-PAL feasibility pilot on conditional forest payments had not published outcome findings (J-PAL, n.d.). Before PES is expanded, independent assessment should establish additional conservation benefits, the fairness of contractual terms, protection of legitimate land and resource rights, and the feasibility of monitoring obligations over time.

The Green Credit Programme uses incentives rather than continuing payments for ecosystem services. Rules issued on 29 August 2025 introduced a five-year requirement and minimum canopy density of 40% before specified tree-plantation credits can be claimed. Eligible credits are generally non-tradable except within corporate groups and may be used once towards permitted obligations, including specified compensatory-afforestation or CSR requirements. One green credit is available for each qualifying new tree aged more than five years, subject to the restoration requirements. The applicant must establish and maintain the plantation (MoEFCC, 2026b; Sirur, 2025). These requirements are more demanding than awarding credits solely for planting seedlings. Nevertheless, canopy density cannot demonstrate native species recovery, wetland restoration or the ecological condition of grasslands. Questions concerning compliance with existing community rights also require explicit safeguards. Green credits should not be represented as compensation for biodiversity loss that the credited activity cannot replace.

Private finance presents a related challenge. Through its work on CSR, BIOFIN developed five detailed proposals for biodiversity projects and a separate rehabilitation proposal concerning the Koyna–Chandoli wildlife corridor in Maharashtra (BIOFIN India, n.d.). This establishes project-development activity, although it does not demonstrate that the proposed resources were fully raised or that restoration outcomes were achieved. CSR and blended finance may support appropriate projects, but some important ecosystems provide public benefits without generating revenue streams attractive to investors. Wetland hydrology, traditional crop diversity and breeding habitats are examples where continued public finance may remain indispensable.

The contribution expected from businesses also extends beyond financing conservation projects. Target 15 encourages large companies and financial institutions to assess and disclose their biodiversity impacts, dependencies and risks, including those associated with supply chains (CBD, 2022). Accordingly, private financing claims require verified baselines, transparent contracts, disclosure of negative impacts and safeguards against double-counting. Investment in restoration cannot be used to excuse avoidable ecological damage elsewhere. Corporate accountability and additional financial mobilisation must be pursued together.

FINANCING CONSERVATION ACROSS DIFFERENT ECOSYSTEMS

An important limitation of forest-oriented financing instruments is their restricted applicability to India's other ecosystems. Forest cover and plantations figure prominently in CAMPA, fiscal-transfer calculations and green credits. Conservation requirements, however, also extend to wetlands, natural grasslands, river systems, floodplains, high-altitude meadows, coastal mudflats, seagrass beds and coral reefs. Restoration techniques and indicators suitable for one ecosystem cannot automatically be applied to another.

India does have dedicated programmes extending beyond forests. The National Plan for Conservation of Aquatic Ecosystems supports wetland management, while the Mangrove Initiative for Shoreline Habitats and Tangible Incomes (MISHTI) addresses mangrove restoration (MoEFCC,

2026a). Coastal financing has also undergone a significant policy development. On 30 September 2026, MoEFCC launched implementation guidelines for National Coastal Mission 2.0, with an approved Central Sector outlay of ₹767 crore through 2030–31 across nine coastal states and four Union Territories. Its stated remit includes ecosystem restoration, biodiversity conservation, pollution management, coastal resilience, research and capacity-building (MoEFCC, 2026d). Together, these programmes establish a policy basis for financing ecosystems that cannot be conserved through afforestation alone.

The implementation record, however, raises questions about the reliability of annual financing. PRS Legislative Research (2025, 2026) reports that the National Coastal Mission spent approximately ₹28 crore against a ₹200-crore budget estimate in 2021–22. In 2024–25, actual expenditure was approximately ₹8 crore against an initial estimate of ₹50 crore; the 2026–27 allocation is ₹10 crore. The ministry attributed part of the earlier funding difficulty to the withdrawal of proposed World Bank assistance (PRS Legislative Research, 2026). Against this background, the ₹767-crore approval for Mission 2.0 is a significant commitment whose implementation must be assessed through subsequent allocations, disbursements and ecological results.

Assessing adequacy across ecosystems is further complicated by the distribution of expenditure among Union ministries, state governments and sectoral programmes. Fisheries, irrigation, pollution control, disaster management and agricultural schemes may all affect biodiversity, but their relevant spending is not brought together in a transparent ecosystem-wise account. Without comparable figures for requirements and expenditure, the extent of underfunding for individual habitats cannot be established with confidence. Reporting must therefore connect financial allocations to ecosystem-specific indicators: tidal exchange and sediment movement in coastal habitats; water regimes, pollution and aquatic biodiversity in wetlands; native vegetation and grazing regimes in grasslands; and the conservation of locally adapted crop varieties in agricultural landscapes. Financing and performance reporting should reflect the ecological needs of each habitat, including improvements that cannot be measured through plantation counts.

ACCESS AND BENEFIT SHARING AND THE FUNCTIONING OF BMCS

India's access and benefit-sharing system offers an important institutional route for linking the commercial use of biological resources with benefits for legitimate claimants. Under the Biological Diversity Act and applicable rules, users of biological resources or associated knowledge may be required to share benefits with eligible communities and other rights-holders. India's first national Nagoya Protocol implementation report, covering November 2017 to December 2025, recorded 12,830 ABS approvals, comprising 5,913 issued by the NBA and 6,917 by state or Union Territory authorities. It also reported 3,556 internationally recognised certificates of compliance, representing over 60% of the global total (MoEFCC, 2026c).

The official report recorded ₹216.31 crore mobilised through NBA approvals, of which ₹139.69 crore had been disbursed to claimants, together with a further ₹51.96 crore generated by state-level approvals. Non-monetary benefits featured in another 395 NBA approvals (MoEFCC, 2026c). These achievements demonstrate the administrative reach of India's ABS regime, although the sums accumulated over approximately eight years remain modest compared with the NBSAP's projected annual requirement. Furthermore, aggregate receipts do not disclose the geographical distribution of benefits, delays in disbursement or the extent of recipient control over their use. ABS should therefore be valued primarily for its potential to recognise community rights and share proceeds fairly, rather than as a major substitute for public conservation finance.

Biodiversity Management Committees (BMCs) constitute the local institutional foundation of this system. Established under the Biological Diversity Act, they contribute to conservation, record locally held biological resources and knowledge, and participate in relevant benefit-sharing processes. According to the NBA, **276,653 BMCs** had been constituted across 28 states and eight Union Territories as of 6 October 2026. The Authority separately reported **272,648 People's Biodiversity Registers (PBRs)** as of 28 July 2026 (NBA, 2026a, 2026b). These totals demonstrate the impressive scale of the institutional network created for local biodiversity governance.

However, the national totals cannot establish whether all legally required committees have been constituted or whether existing BMCs are functioning effectively. The two series have different reporting dates and cannot be combined into a reliable nationwide register-completion percentage. The national BMC count also provides no information on which committees require reconstitution, maintain functioning accounts, meet regularly or possess the capacity to negotiate and administer benefits. Establishing legal coverage also requires careful attention to Section 41 of the Biological Diversity Act, as amended in 2023. Committees are mandated at the gram-panchayat level and specified urban local-body levels, while states may additionally create them at intermediate and district panchayat levels. Comparing the NBA total against an indiscriminate count of villages and every panchayat tier would therefore be misleading (Government of India, 2023; NBA, 2026c).

State-level evidence clarifies the distinction between formal constitution and effective functioning. West Bengal's Biodiversity Board lists 3,830 BMCs for 3,830 local bodies, but also identifies **400 committees awaiting reconstitution**: 300 at block level and 100 in urban local bodies. Approximately 10.4% of the listed committees thus required renewal even though the state reported complete formation (West Bengal Biodiversity Board, n.d.). By comparison, Assam lists 2,549 BMCs and Jharkhand 4,689, with their respective biodiversity boards reporting complete constitution against the categories of local bodies covered in those state records (Assam State Biodiversity Board, n.d.; Jharkhand Biodiversity Board, n.d.). State reports therefore demonstrate substantial formal coverage in several jurisdictions while reinforcing the need for a national assessment of legally required coverage, committee renewal and operational status.

Differences between BMC and PBR counts raise further concerns about institutional activity. The NBA lists 2,260 committees but 199 PBRs for Manipur; the respective figures are 12,008 and 10,540 for Chhattisgarh, and 1,200 and 1,034 for Kerala (NBA, 2026a, 2026b). The separate update dates preclude precise completion-rate calculations, but the sizeable differences point to uneven documentation. More direct evidence comes from the Legal Initiative for Forest and Environment's field investigation in 2021, published in 2022. Among the surveyed bodies, none of ten identified BMCs in Howrah was functioning; eight of nine in Nadia were inactive, while the ninth could not be verified; and none of six identified BMCs in Darjeeling was operational. Consulted local bodies also lacked familiarity with ABS (Legal Initiative for Forest and Environment (Das, 2022). These findings describe the sampled locations at the time of fieldwork and cannot be projected as a statewide or current national rate. They nevertheless establish that formal constitution may coexist with administrative inactivity.

The available evidence on meetings and training points in the same direction. Kerala's *Economic Review 2025* records 358 BMC meetings during its reporting period within a network of 1,200 committees, in addition to 40 updated PBRs and six training programmes in 2024–25 (Kerala State Planning Board, 2026). Since one committee may convene more than once, meeting totals do not reveal the number of active committees. A separate 2024 study involving 180 members from six Kerala districts found that 18.89% had received no conservation training, 32.22% had attended one session, 40% two sessions and 8.89% at least three (Victor et al., 2024). The study's restricted sample does not establish prevalence across India, but it

documents differences in preparation among committee members. This distinction reflects Kohli and Bhutani's (2014) criticism of an approach that places greater emphasis on committee and register counts than on accountable local biodiversity governance.

Strengthening BMCs consequently requires an operational assessment, not another constitution drive alone. State boards should document valid committee terms, representation of women and resource-dependent groups, meeting records, PBR quality, access controls for sensitive knowledge, functioning Local Biodiversity Fund accounts where applicable, actual conservation activities and beneficiary-level disbursements. The voluntary ABS certification scheme launched in June 2026 with the NBA and Quality Council of India may encourage compliant corporate participation, although certificates should be assessed alongside independently demonstrable benefits (Biodiversity Finance Initiative, 2026). BIOFIN's separately reported USD 29.5 million in ABS accruals as of December 2025 uses a different reporting basis from the official Nagoya statistics and should not be added to them (Biodiversity Finance Initiative, 2025).

The Cali Fund's planned allocation for Indigenous Peoples and local communities makes the effectiveness of local institutions especially important. BMCs could assist eligible beneficiaries, but they cannot be presumed to be the sole, mandatory or preferred channel under arrangements that remain under international discussion. Indigenous institutions and other legitimate rights-holders must be able to participate according to applicable rights and procedures. Greater digitisation of PBRs may support administration, provided confidential traditional knowledge is protected against unauthorised access and uncompensated commercial use.

CIVIL SOCIETY'S RESPONSIBILITIES IN BIODIVERSITY FINANCE

Local institutions cannot fulfil these responsibilities without technical support, independent scrutiny and access to information. Civil society therefore has a substantive role in biodiversity finance beyond being named as an implementation partner. Four functions are particularly important.

- **Verification.** Universities, independent research institutions and community monitors can assess habitat condition, plantation survival, PES outcomes and the receipt of ABS benefits. Credible verification requires access to expenditure records, site information and baseline data. Organisations implementing a project must not be its sole evaluators.
- **Delivery.** Accountable civil society organisations can provide ecological expertise, legal assistance and administrative support to BMCs, Joint Forest Management institutions and other community organisations undertaking conservation. Such assistance must strengthen the powers of the responsible institutions without displacing the rights of communities to determine the use of their resources.
- **Aggregation.** Small-scale conservation projects may lack the capacity to meet corporate or institutional appraisal requirements. Transparent intermediaries can assemble compatible activities into viable financing proposals, provide technical documentation and reduce transaction costs without transferring decision-making powers away from communities.
- **Safeguarding.** Organisations experienced in customary tenure, forest rights and community livelihoods can identify exclusion, disputed representation or proposed restrictions on resource access before financial agreements are signed. They can also support grievance procedures and monitor whether intended recipients receive the promised benefits.
- The NBSAP should recognise and finance these roles, including access to project records and resources for repeated field assessments. Monitoring arrangements must preserve the independence of organisations assessing programme results.

MEASURING THE EFFECTIVENESS OF BIODIVERSITY FINANCE

The instruments discussed above differ in how they mobilise money and what they are designed to achieve. Their performance can nevertheless be assessed through four complementary dimensions. **Financial performance** requires information on commitments, approved allocations, releases, expenditure, additional resources mobilised and long-term maintenance costs. **Ecological performance** concerns changes in habitat condition, native biodiversity and ecosystem functioning measured against documented baselines. **Community outcomes** include informed participation, recognised rights, actual benefit transfers and the effects of conservation arrangements on livelihoods.

Institutional performance concerns the capacity, transparency and accountability of the organisations responsible for planning, implementation and monitoring.

These dimensions must be applied to the purpose of each instrument. CAMPA should be judged against ecological losses and verified restoration outcomes, while PES requires evidence that financial incentives have secured conservation beyond what would otherwise have occurred. ABS needs a traceable account of collections and benefits reaching claimants. Ecological fiscal transfers should be evaluated for their effects on policy and forest condition without mischaracterising unconditional tax devolution. For corporate financing, independent scrutiny should cover the environmental effects of the company's wider operations as well as the outcomes of the project it funds.

A national biodiversity expenditure tracker should bring these measures together without counting the same expenditure repeatedly as separate climate, restoration and biodiversity finance. Accessible reports should also identify activities that do not meet their intended objectives and ecological damage that restoration cannot fully offset. Reliable measurement would allow India to direct limited resources towards interventions with demonstrable ecological and social value.

THE MAJOR CHALLENGES FACING BIODIVERSITY FINANCE IN INDIA

The preceding assessments identify constraints that cannot be resolved by raising finance alone. India must reconcile its development priorities and fiscal limitations with the ecological requirements of conservation, the complexity of federal administration and the rights of resource-dependent communities. These challenges influence both the availability of funds and their effectiveness after disbursement.

Competing demands on public resources. Biodiversity conservation must compete for funding with healthcare, education, social protection, infrastructure and climate adaptation. State governments have differing fiscal capacities, while many ecological benefits extend beyond their administrative boundaries and become visible only over long periods. Projects that generate public benefits without dependable commercial revenue cannot reasonably be expected to attract private finance on their own. Sustained domestic public investment and credible international assistance therefore remain necessary.

Development policies that generate additional ecological costs. Roads, settlements, energy projects, extraction, intensive farming and tourism may impose damage that public restoration programmes are subsequently expected to repair. Environmental impacts are often considered within project-specific approvals, while the cumulative consequences for landscapes, species and livelihoods are harder to account for. The reform of harmful incentives and early integration of biodiversity into development decisions are consequently central to controlling future financing needs.

Fragmented responsibilities. Forests, wetlands, rivers, fisheries, agriculture, urban ecosystems and coastal areas fall under different

authorities and financing arrangements. Ecological boundaries seldom coincide with those of districts, states or line departments. Restoration in one administrative jurisdiction may be compromised by pollution, altered water flows or land-use decisions elsewhere. Integrated landscape and river-basin planning require agencies to agree on shared objectives, expenditure responsibilities and monitoring systems.

Dependence on natural resources and unequal access to decision-making. Fisheries, grazing, non-timber forest products and use of common lands provide important livelihood support. Conservation measures that restrict such activities can shift immediate economic costs onto households while benefits are distributed more widely. The problem becomes especially serious when short-term employment is offered alongside long-term restrictions on traditional resource use. Fair finance must therefore cover consultation, applicable consent requirements, tenure assessment, livelihood support, grievance redress and the equitable distribution of benefits. BMCs and other local bodies require the authority and capacity to represent rights-holders effectively.

Overlapping legal and institutional authority. Biodiversity committees, forest authorities, local governments and institutions operating under the Forest Rights Act have different statutory responsibilities. Administrative control over land does not automatically settle customary claims or determine who is entitled to consent, compensation or benefit sharing. Project preparation must identify the applicable legal requirements and legitimate decision-makers before contracts are concluded. Failure to do so can create conflict, exclude intended beneficiaries and undermine implementation.

Inadequate ecological evidence and monitoring capacity. Satellite imagery can track land cover and canopy, but cannot independently establish ecological integrity, the recovery of aquatic habitats, species populations, soil biodiversity or genetic diversity in crops. The CBD's 2026 global review identifies extensive weaknesses in long-term ecosystem monitoring (CBD, 2026a). India faces the additional task of creating comparable baselines and maintaining field monitoring across diverse ecosystems and administrative agencies. The Green India Mission audit demonstrates how weak coordination, insufficient funding and inadequate evaluation can leave claimed achievements unsupported by observed ecological change (CAG, 2026).

Administrative delays and uncertain continuity. A financial commitment is not necessarily followed by a timely release or effective expenditure. CAMPA utilisation, the National Coastal Mission's earlier spending record and the Green India Mission's financing difficulties illustrate different forms of this problem. Restoration also requires maintenance beyond the usual duration of a project or annual budget cycle. Unreliable disbursement can interrupt monitoring, weaken community confidence and erode ecological gains already achieved.

Climate risks and the durability of investments. Floods, heat, drought, fire, coastal erosion and shifting species distributions may damage restored habitats or change the ecological suitability of intervention sites. Consequently, finance plans must account for long-term maintenance, changing risk conditions and coordination with climate adaptation. Where a project legitimately contributes to both climate resilience and biodiversity conservation, reporting must recognise the shared benefits without presenting the same expenditure as two separate additions to available finance.

Taken together, these challenges show why increased mobilisation, although essential, cannot guarantee effective implementation. India's biodiversity financing arrangements must also be capable of managing conflicts between development priorities, maintaining ecological evidence, protecting legitimate rights and financing conservation over the timescales on which ecosystems recover.

POLICY PRIORITIES FOR INDIA

The immediate agenda ought to follow from the weaknesses identified in existing instruments and the structural conditions under which they operate.

1. Establish a national biodiversity expenditure and outcomes account. MoEFCC and the Ministry of Finance should jointly publish comparable annual figures by ministry, state, scheme and funding source, distinguishing estimated requirements, allocations, releases, utilisation and independently verified outcomes. BIOFIN's mapping of 116 schemes provides a starting point for this work. Common rules are needed to avoid counting the same resources under multiple funding categories.

2. Convert the NBSAP costing into funded implementation commitments. Each national target should specify responsible departments, annual funding requirements, available allocations, milestones and measurable results. Periodic updates to finance needs and expenditure assessments should use compatible accounting definitions so that the remaining gap can be calculated without mixing incompatible historical and projected series.

3. Reform harmful incentives with livelihood protection. Agriculture, water, fisheries, energy and infrastructure support should be examined for adverse biodiversity effects. Regionally tested reforms should preserve essential farm and household security while rewarding practices that improve soil, water, habitat and biological diversity.

4. Make ecological condition central to restoration finance. CAMPA, the Green India Mission, PES and green-credit activities should report appropriate baselines, native species, ecosystem functions and changes sustained over time. Plantation area and fund utilisation should remain administrative indicators rather than substitutes for evidence of ecological recovery. Independent evaluation must be funded as part of implementation.

5. Provide ecosystem-specific financing and reporting. Wetlands, grasslands, rivers, coastal and marine habitats, and agricultural biodiversity require programmes and indicators suited to their conservation needs. Annual reporting should identify how much relevant expenditure supports each ecosystem, from which departments and with what results. For National Coastal Mission 2.0, the approved multi-year outlay should be accompanied by clear annual release and implementation records.

6. Audit the operational status of BMCs nationwide. State biodiversity boards should reconcile BMC records with legally relevant local bodies and publish committee-level information on reconstitution, meetings, membership, training, PBR quality, accounts and conservation activities. Annual disclosure would make administrative inactivity visible even where formal constitution is complete.

7. Make benefit sharing transparent and accessible. NBA and state reports should identify collections, disbursements, beneficiary categories and time taken to deliver benefits, while protecting personal information and sensitive traditional knowledge. Any arrangements for future Cali Fund resources must respect legitimate rights-holders and ensure that the intended communities can participate in decisions about fund use.

8. Define the responsibilities of private finance and civil society. Corporate-funded activities must meet independent ecological and social safeguards, disclose remaining environmental impacts and demonstrate genuine additionality where claimed. Civil society organisations should receive an adequately funded role in community support and independent monitoring, with safeguards against conflicts between implementation and evaluation.

9. Institutionalise a common performance report. Each major financing programme should publish an annual, independently reviewable assessment covering the four dimensions set out in Section 8, with clear baselines, assigned reporting responsibilities and funds for long-term ecological and

community monitoring. This would allow programmes to be compared without treating all ecosystems or financing instruments as identical.

CONCLUSION

India has established much of the planning and institutional architecture needed to implement the GBF. The remaining task is to turn its costed commitments, expenditure mechanisms and local governance arrangements into financed actions whose results can be independently demonstrated.

The missed 2025 international-finance milestone strengthens the case for fulfilment of global commitments without removing India's responsibility to improve domestic implementation. India's priorities are to calculate its current financing deficit accurately, reform public incentives that damage biodiversity, mobilise additional resources, ensure that financing reflects the requirements of different ecosystems, and make local institutions capable of delivering fair benefits. The ultimate measure of success is whether money committed to biodiversity produces verifiable ecological improvements while protecting the rights and livelihoods of communities who depend on the resources being conserved.

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Current Context



Weak Monsoon, Strong El Niño: What India's Dry Year Means for Water, Food and the Year Ahead

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India's 2026 monsoon was one of its weakest in years. At the same time, El Niño in the Pacific Ocean is getting stronger and is expected to peak around December. This is a "double whammy" for India. The rains have already fallen short, and the winter crop season now faces a warmer and drier winter. A warmer winter also means less Himalayan snow, which matters for water in the north. Experts also worry about the 2027 monsoon.

WHAT IS EL NIÑO?

El Niño is a natural climate pattern. The surface water in the central and eastern Pacific Ocean becomes much warmer than normal. This changes wind and rain patterns across the world. Some regions get floods and others get droughts. In South Asia, El Niño usually weakens the monsoon.

The numbers for 2026 are large:

- The World Meteorological Organization (WMO) said on 8 October that Pacific sea-surface temperatures are forecast to reach record levels in October–December 2026, with El Niño expected to peak in December (WMO 2026).
- The WMO chief said that El Niño is firmly established and strengthening rapidly, with a near-100% chance of lasting until February 2027, and it could become one of the strongest since at least 1950 (Akashvani News, 2026).
- The WMO forecast says the Niño 3.4 temperature anomaly (the key measure of El Niño) could reach about +3.7°C in October–December (WMO 2026).
- You may see the term "super El Niño" in the news. The WMO says this term is not part of its official classification. It sorts events as weak, moderate, strong or very strong. Even so, forecasters agree that this event is exceptional (WMO 2026).
- El Niño does not create new heat on its own. It moves heat around, and it adds to the long-term warming caused by human activity. The WMO has said this El Niño is developing against a backdrop of unprecedented ocean heat and rising temperatures. So, the world is likely to see more extreme heat in the coming months (WMO 2026).

INDIA'S 2026 MONSOON

- The monsoon brings about 70% of India's yearly rain. It matters for farming, drinking water and power.
- The season started slowly. The monsoon reached Kerala on 4 June, three days later than normal and nine days after the IMD's forecast date. In May, the India Meteorological Department (IMD) had already forecast below-normal rain at 90% of the long-period average (LPA) (Sangomla, 2026; Business Today, 2026).

The final numbers confirm this:

- India received about 87% of its LPA from June to September. That is a 13% deficit, making 2026 the fourth-lowest monsoon since 2001 and the 13th lowest since 1901 (The Wire Staff, 2026).
- Another report puts the total at 759.4 mm against an LPA of 868.6 mm, a 12.6% deficit and the lowest since 2015 (SuperKalam, 2026).
- The deficit was uneven. East and northeast India recorded their lowest monsoon rainfall since 1901. The southern peninsula had a 24.3% deficit (The Wire Staff, 2026; SuperKalam, 2026).
- By mid-September, 24 of India's 36 meteorological subdivisions had rainfall deficits above 10% (FPJ Web Desk, 2026).

The IMD also expects October to be dry. It forecasts October rain below normal, at less than 85% of the LPA (SuperKalam, 2026).

A MISSING HELPER: THE INDIAN OCEAN DIPOLE

A positive Indian Ocean Dipole (IOD) can reduce El Niño's harm to the monsoon. This year it did not help much. One forecaster noted that the IOD stayed mostly neutral despite the strong El Niño, so it could not offset El Niño's effect (Sharma n.d.).

WHY THE SEASON WAS HARD TO READ

The monsoon did not fail in a smooth way. Early on, the deficit was large. A report said the cumulative deficit was 42.8% below normal until 22 June. Rain then recovered in July. July rainfall was 2.4% above the LPA. But August and September could not close the gap (SuperKalam, 2026).

DRY YEAR, BUT STILL FLOODS

A weak monsoon does not mean no floods. In a weak monsoon year, rain often comes in short, heavy bursts. This can cause floods and landslides even in places with a seasonal deficit.

- In July, Assam faced floods in 12 districts despite a 30% rainfall deficit (Sangomla, 2026).
- The same report named other states hit by extreme rain, floods or landslides: Mizoram, Jammu and Kashmir, Himachal Pradesh, Gujarat and Maharashtra (Sangomla, 2026).
- Bihar faced severe floods from heavy rain and flash floods in Nepal, yet it had a 35% rainfall deficit (Pillai, 2026).

The lesson is simple. Total rain is not enough to judge a season. The timing and spread of rain matter just as much. Warmer air holds more moisture, so global warming makes short, intense downpours more likely, even when the season is dry overall.

RESERVOIRS AND WATER

Reservoirs store monsoon water for irrigation, drinking and hydropower. India started 2026 in a fairly good position. On 16 April, storage in the 166 reservoirs monitored by the Central Water Commission (CWC) was about 116% of the level a year earlier. This gave the country a cushion (Central Water Commission, 2026).

That cushion is now under pressure. A weak monsoon means less water flowing into reservoirs just before the dry months. Hot El Niño summers also raise power demand, and weaker rain drains the reservoirs that hydroelectric plants depend on (Bhaisora, 2026).

RABI CROPS: THE NEXT TEST

India has two main crop seasons:

- **Kharif** crops (rice, cotton, pulses, oilseeds) are sown with the monsoon and harvested in autumn.
- **Rabi** crops (wheat, mustard, gram, potato, maize, pulses) are sown in October–December and harvested in spring. They need cool weather and irrigation water.

Kharif is already under pressure. The US Department of Agriculture expects India's rice output to fall to 147 million tonnes from 154 million tonnes, and maize to 50 million tonnes from 55.1 million tonnes. Sown area was not much lower, at only 1.4% below last year. The problem is yield. Dry spells broken by heavy downpours hurt crops (FPJ Web Desk 2026).

Rabi crops face a different risk. A strong El Niño can bring a shorter and warmer winter. Analysts warn this may hurt wheat, mustard, pulses, potato, onion, garlic and spices. Wheat is especially sensitive to heat during grain filling, so even a few warm days in February–March can cut yields. Low soil moisture and low reservoir levels add to the risk.

Some analysts see a repeat of 2015–16. They fear a double whammy of two weak seasons in a row, with lower crop output, food inflation and higher imports (FPJ Web Desk 2026).

There is one more point. The northeast monsoon (October–December) brings rain to south India. In El Niño years it can be heavy in the far south, so some analysts expect floods there. This is a medium-confidence view. A heavy northeast monsoon could help the south's reservoirs, but it would not fix the deficit elsewhere.

FOOD PRICES AND RURAL INCOMES

Food prices may rise, though the government has tools to limit this.

- The FAO world food price index reached 133.3 points in August, it's highest since November 2022. Global prices are rising because of weather and trade disruption (FPJ Web Desk 2026).
- After the last strong El Niño, retail food inflation averaged above 8.5% between July 2023 and December 2024.
- A Kotak Mutual Fund report estimates that food price pressure from El Niño could add about 20–25 basis points to headline inflation. Vegetables are the most sensitive, since they spoil quickly and depend on steady weather (Ojha, 2026).
- India also depends on imports. It imported 16.9 million tonnes of vegetable oils in 2025–26 and 7.3 million tonnes of pulses in 2024-

25. A poor crop and costlier global supply together make these imports more expensive (FPJ Web Desk 2026).

Buffers. India has some protection. Analysts note that it holds large buffer stocks of rice, wheat and pulses. This is why cereal prices may stay steadier than vegetables and edible oils.

Rural incomes. A farmer's income depends on both yield and price. When yields fall, farmers earn less, even if prices rise. Small farmers with no irrigation are hit hardest. This is why crop insurance, rural job schemes and timely relief matter. Weak rural income can also slow demand for tractors, fertiliser and consumer goods.

A WARMER WINTER AND THE HIMALAYAN SNOW

El Niño's effects will not end with the monsoon. Analysts expect El Niño to peak after the monsoon, which means warmer winters with low snowfall, and this may spill over into the 2027 monsoon.

This matters because Himalayan snow works like a water bank. It melts slowly in spring and summer and feeds the Indus, Ganga and Brahmaputra systems. Less snow means less meltwater later, for drinking water, irrigation and hydropower.

THE JAMMU AND KASHMIR STUDY

New research shows the mountains were already warming before this El Niño. A study by IIT Kharagpur and the IMD, published in *Scientific Reports*, used data from 1980 to 2024 at ten IMD stations across Jammu and Kashmir. Its main findings: Warming is uneven. Mountain areas are warming faster than the plains. Scientists call this elevation-dependent warming (Deccan Herald 2026).

- Pahalgam and Gulmarg warmed by nearly 1°C over two decades. Bhaderwah warmed by about 0.3°C per decade (Deccan Herald 2026).
- Low-lying areas stayed stable. The Jammu plains showed a slight cooling of about 0.1°C per decade (Gopikrishnan et al., 2026).
- Night-time temperatures are rising faster than daytime temperatures.
- The authors warned of serious implications for glaciers, snow cover, river flows, biodiversity and water security, affecting millions of people.
- They also noted a gap in the data: observations above 3,000 metres are limited. They called for more high-altitude weather stations. The researchers say local factors such as falling humidity and changes in how much sunlight the ground reflects help explain the pattern (Gopikrishnan et al., 2026).
- Put the two stories together. The Himalayas are warming over the long term. A warm, dry El Niño winter then adds a short-term push. Together they can mean thinner snow, earlier melt and more stress on rivers in northern India next summer.

THE BIG QUESTION: THE 2027 MONSOON

The 2027 monsoon depends on how fast El Niño fades and on the Indian Ocean Dipole. Historically, India's monsoon often recovers after an El Niño year, but this is not guaranteed. Some analysts rate the threat to the 2027 monsoon as medium-confidence and dependent on how quickly El Niño decays and on the IOD.

Water managers should plan for a possible weak start to 2027. Key signs to watch are the IMD's April forecast, snowpack levels and reservoir storage next spring.

WHAT INDIA CAN DO NOW

These steps are widely discussed by experts and are reasonable and low-regret:

- **Update crop plans.** Promote short-duration, drought-tolerant and heat-tolerant varieties. The government has identified nearly 200 districts as highly vulnerable to El Niño impacts on agriculture and has prepared contingency plans.
- **Use water carefully.** Prioritise drinking water, then irrigation for critical stages. Micro-irrigation saves water.
- **Keep supply lines open.** Manage stocks and keep import options flexible for edible oils and pulses.
- **Protect farmers.** Speed up crop insurance payouts and rural employment work.
- **Prepare for extremes on both sides.** Plan for heat in the plains, heavy rain in the south and flash floods in the hills.
- **Improve data.** More high-altitude stations and district-level forecasts would help planners.

CONCLUSION

The 2026 monsoon ended about 13% short, with the east and northeast the driest on record. The Pacific is now heating towards a possible record El Niño. For India, the next month's matter most: the rabi sowing season, winter temperatures, Himalayan snow and then the 2027 monsoon.

This year also shows that climate risk is not one-sided. India has faced drought-like deficits and flash floods in the same season. The country has buffer stocks, forecasting tools and contingency plans to cope. How well it uses them in the coming months will decide how much of this shock reaches farmers and households.

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Hydropower Expansion and the Production of Risk in the Hindu Kush Himalaya: A Case Study of the 2026 Flood in Rasuwa, Nepal

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Hydropower Expansion and Changing Hazard Conditions in the Hindu Kush Himalaya

Hydropower development has expanded rapidly across the Hindu Kush Himalaya (HKH) during the last two decades. The attraction is evident. Mountain rivers provide substantial generation potential, while electricity from hydropower can strengthen domestic energy security, reduce dependence on imported fossil fuels and the greenhouse-gas emissions and air pollution associated with their use, and support cross-border power trade. For countries seeking simultaneously to increase energy access and reduce carbon-intensive generation, hydropower has therefore acquired considerable economic and strategic importance (International Centre for Integrated Mountain Development [ICIMOD], 2025). The regional potential is substantial, with hydropower being an important component of the more than 3.5 TW of renewable-energy potential identified across the eight HKH countries (ICIMOD, 2025). This expansion, however, is occurring during a period of pronounced environmental change in the high mountains. The Hindu Kush Himalayan cryosphere is losing ice at an accelerating rate. Glacier area declined by approximately 12 per cent between 1990 and 2020, with marked regional variation, while field observations indicate that glacier mass loss has accelerated substantially since the beginning of this century (Azam, 2026; Maharjan & Sherpa, 2026). Furthermore, thawing permafrost, destabilisation of steep slopes, enlargement of glacial lakes, altered sediment movement and increasingly complex interactions between rock, ice and water are changing hazard conditions across many high-altitude catchments (Li et al., 2022). Infrastructure planned on the basis of earlier environmental conditions may consequently remain in place for decades while the physical conditions surrounding it continue to change. The intersection of these two processes requires closer attention. Much Himalayan hydropower infrastructure is necessarily located within steep river valleys. The same valleys also accommodate roads, bridges, settlements and transmission networks associated with wider regional development. Consequently, an extreme event originating far above a project site can affect several interconnected systems during a single hazard cascade. The concern is not confined to protecting individual dams or powerhouses. It extends to the growing concentration of strategic infrastructure within mountain environments where the nature and magnitude of hazards are changing (Li et al., 2022). Recent disasters have demonstrated this problem with increasing clarity. The 2021 rock–ice avalanche in Chamoli destroyed hydropower infrastructure in Uttarakhand and left more than 200 people dead or missing. In 2023, the South Lhonak outburst flood travelled down the Teesta valley in Sikkim and destroyed the Teesta III project at Chungthang. Rasuwa in Nepal was affected by a major glacier-related flood in July 2025 and again by a destructive rock–ice collapse and downstream flood in August 2026. These events differed in their physical causes. Their geographical consequences, however, reveal a common concern: large infrastructure networks have become established within Himalayan valleys exposed to several forms of rapidly evolving high-mountain hazard (Allam et al., 2026; Sattar et al., 2021). The question raised by this pattern is therefore not whether hydropower should form part of the Himalayan energy transition. It already does, and its economic importance is unlikely to diminish. The more difficult question concerns the manner in which the benefits and risks of that transition are being distributed. Electricity generated in mountain valleys contributes to national energy systems and, increasingly, to regional electricity markets. The hazards associated with its location, however, are experienced within particular valleys and by particular populations. Decisions concerning project siting, acceptable levels of risk, reconstruction and investment are made through regulatory and financial institutions that do not distribute authority or consequences evenly. Examining this disparity requires

attention to the political and institutional processes through which exposure is created, accepted and, in some cases, reproduced. The catastrophic flood in Rasuwa, Nepal, in August 2026 provides a recent case through which this wider regional problem can be examined.

Rasuwa 2025–2026: Repeated Exposure and Institutional Lock-in

The Rasuwa corridor had initially been damaged in July 2025. Water stored on the surface of the Purepu Glacier in Tibet drained suddenly and generated a destructive flood that entered Nepal through the Lende–Bhote Koshi system. The event damaged the Rasuwagadhi border area, transport links and hydropower infrastructure, including the 111 MW Rasuwagadhi project (National Disaster Risk Reduction and Management Authority [NDRRMA], 2025). Repairs followed, and Rasuwagadhi resumed partial electricity generation in December of the same year (Allam et al., 2026). Fourteen months after the 2025 event, the corridor was devastated again. This time the initiating process was different. On 26 August 2026, a very large mass involving rock and ice failed in the high mountains close to the Nepal–China frontier. The moving material accelerated downslope, incorporated additional debris and evolved into a destructive flow that continued through the river system. Scientific reconstruction indicates that glacier recession, permafrost degradation, geological weaknesses and other long-term changes contributed to the instability, while neither exceptional rainfall nor an earthquake was identified as the immediate trigger (Li et al., 2026; Zhao et al., 2026).

The consequences of the 2026 flood show how this changing hazard environment intersects with existing patterns of infrastructure development. Nepal's post-disaster assessment covered thirteen hydropower schemes whose capacities together amounted to 759.03 MW. Direct losses to energy assets were valued at approximately US$889 million, while restoring and reconstructing the sector was projected to require around US$2.58 billion (NDRRMA, 2026). The assessment identified 8,317 affected households, extensive damage to buildings and the loss of thirty-three motorable bridges, indicating how a single event disrupted settlements, transport and electricity infrastructure along the same river corridor (NDRRMA, 2026).

The scale of these losses is only part of the issue. Rebuilding after the 2025 flood was understandable. Electricity generation had to be restored, substantial capital was already invested and engineering modifications may have been expected to reduce the identified danger. Yet relocation of an established hydropower project is not simply a matter of selecting a safer site. By the time a plant becomes operational, licences, electricity-sale arrangements, debt and associated infrastructure are already tied to its approved location.

Recent analysis of Rasuwagadhi draws attention to this constraint. In Nepal, generation licences are connected to specified sites and may extend for up to fifty years. Power-purchase agreements commonly run for twenty-five to thirty years, while project finance depends upon the income expected from those agreements (Allam et al., 2026; Government of Nepal, 1992). Moving a project can therefore require surrender or alteration of existing permissions, renegotiation of tariffs, further environmental assessment and new arrangements with lenders. Repair at the approved site may preserve much of the existing legal and financial structure. Institutional arrangements intended to secure investment can consequently make withdrawal from a site more difficult even when later evidence indicates greater danger than was recognised when the project was approved (Allam et al., 2026).

Uneven Distribution of Benefits and Risk

The institutional constraints surrounding relocation lead to a second question: whether the groups most exposed to hydropower-related risk exercise comparable influence over the development from which that risk arises. Hydropower benefits operate across several scales. Electricity supports national consumption and economic activity, while surplus generation can enter regional markets. Developers, financial institutions and governments obtain different forms of economic return. Communities living near project sites may also benefit through jobs, improved access, local services and electricity. These gains, however, are neither uniform nor guaranteed.

Evidence from twelve run-of-river schemes in Nepal's Gandaki basin demonstrates considerable variation between project areas. Local social and political relations influenced both access to benefits and the ability of affected populations to participate effectively in decisions. Hydropower improved services and access in some locations, while in others existing inequalities were reinforced (Crootof et al., 2021).

Disaster risk introduces a further imbalance. The economic value of electricity is dispersed through a much wider territory than the immediate danger associated with the infrastructure producing it. People living or working within exposed valleys face consequences that cannot be reduced to the financial loss carried by the project developer. The relevant issue is therefore not a simple opposition between national benefit and local cost. Both can occur simultaneously. What requires examination is whether populations facing the greatest direct exposure have sufficient influence over decisions that establish, maintain or reconstruct that exposure.

This becomes especially important in the context of renewable-energy expansion. Hydropower can reduce dependence on fossil fuels and the greenhouse-gas emissions and air pollution associated with their combustion. That advantage remains important. It does not, however, determine whether the manner in which a particular project distributes risk is equitable. A transition can be lower in carbon while still retaining substantial spatial inequalities in environmental exposure.

Those inequalities also occur within project-affected communities. Nepal's local-share system allows up to 10 per cent of shares in some hydropower developments to be reserved for purchase by affected residents. An IFC assessment found that the opportunity was not equally accessible: poorer households had less capacity to invest, while some socially and economically disadvantaged participants borrowed money or sold assets to purchase shares without fully understanding the associated financial risk (International Finance Corporation [IFC], 2018). Formal access to a benefit therefore does not ensure equal ability to obtain it.

Exposure is similarly uneven. Residence near the river, dependence upon local land and roads, or employment within project facilities can increase vulnerability irrespective of how much a household has benefited from hydropower. The category of an 'affected community' can thus conceal substantial differences in income, occupation, property ownership and influence. These differences shape both the gains that households can secure and the losses they may have to absorb.

Transboundary Risk and Unequal Access to Information

The 2025 Rasuwa flood exposed a separate problem. Nepalese flood-forecasting officials reported that they had received no advance warning from China and that no mechanism was then in place for immediate notification of an upstream flood. By the time the event was recognised within Nepal's monitoring system, severe damage had already occurred farther upstream (Poudel, 2025).

This is not unique to Rasuwa. Zhang et al. (2023) identified 112 potential GLOFs in the wider Third Pole whose effects could cross an international boundary; 55 were associated with the China–Nepal frontier. Their assessment also identified 105 hydropower projects, more than 5,000 km of roads and over 4,000 bridges within areas potentially exposed to future GLOFs. Although the 2026 Rasuwa disaster arose through a different physical process, the governance problem is comparable: an upstream hazard may develop under one jurisdiction while a substantial share of the downstream exposure lies under another (Zhang et al., 2023).

Regional electricity trade is already creating closer links between national energy systems. Comparable arrangements are required for hazard information. Regular exchange of hydrological, cryospheric and slope-instability data would reduce the present mismatch between transboundary environmental processes and nationally bounded monitoring systems.

Implications for Hydropower Governance

The Rasuwa case points to three areas requiring change. First, the suitability of a project site cannot be regarded as permanently settled when construction is approved. Hydropower assets may operate for several decades, during which glaciers, slopes, sediment regimes and high-

altitude water bodies can change substantially. Periodic reassessment is therefore necessary, particularly following major changes within the upstream catchment or a severe event affecting the same corridor.

Second, reassessment must be capable of altering an earlier decision. Where new evidence indicates that risk has increased materially, regulatory and contractual arrangements should allow redesign, revised operating conditions or relocation. Otherwise, new hazard information may have little practical effect because restoring an existing project remains easier than reconsidering its location. Basin-level assessment is equally important where several power plants and associated infrastructure share exposure to the same upstream processes (Allam et al., 2026).

Third, benefit-sharing must recognise differences within affected populations. Local equity can provide an important opportunity, but it cannot substitute for benefits accessible to households without investment capital. Employment, compensation, community infrastructure and livelihood support remain necessary where economic capacity varies substantially within the same project area (IFC, 2018). These measures do not require a retreat from hydropower. They require institutions that can revise development decisions when the conditions on which those decisions were based have changed.

CONCLUSION

The 2026 Rasuwa disaster demonstrates that Himalayan hydropower risk is shaped not only by the severity of a physical event but also by the arrangements surrounding infrastructure, finance, information and decision-making. Long-term investment can bind projects to particular sites; access to benefits varies within affected communities; and political boundaries can restrict access to information about hazards developing upstream.

Hydropower will remain important to the HKH energy transition. The challenge is to ensure that the institutions governing it can respond to environmental change rather than merely restore earlier patterns of exposure after each disaster. Where mountain conditions are changing, the capacity to reconsider previous decisions becomes part of resilience itself.

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Seen in the Treaty, missing in the Hamlet: What CBD COP17 Holds for India's Particularly Vulnerable Tribal Groups

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ABSTRACT AND KEY MESSAGES

The seventeenth meeting of the Conference of the Parties (COP17) to the Convention on Biological Diversity (CBD) will be held in Yerevan, Armenia, from 19 to 30 October 2026. It will undertake the first global review of the Kunming-Montreal Global Biodiversity Framework (KMGBF) (Secretariat of the Convention on Biological Diversity [SCBD], 2026a; Earth Negotiations Bulletin [ENB], 2025). The Article 8(j) agenda, the guidelines on Indigenous and traditional territories, and the operationalisation of the Cali Fund bear directly on India's 75 Particularly Vulnerable Tribal Groups (PVTGs). This article examines how far these decisions are likely to reach the PVTG hamlet, and identifies four points at which outcomes may fail to arrive: representation, territorial tenure, benefit-sharing and data visibility.

KEY MESSAGES

- Representation: The Subsidiary Body on Article 8(j) is permanent, but its operating rules are still to be decided at COP17, and India does not apply the term 'Indigenous peoples' to its Scheduled Tribes (SCBD, 2026a; International Fund for Agricultural Development [IFAD], 2022).
- Tenure: Habitat rights under Section 3(1)(e) of the Forest Rights Act, 2006 are the domestic instrument that corresponds to Target 3 of the KMGBF for PVTGs. Published official reporting does not provide a consolidated national account of their recognition (MoTA, 2015; SCBD, n.d.-a).
- Benefit-sharing: The Cali Fund is intended to direct at least half of its resources to Indigenous peoples and local communities, yet private-sector contributions remain very limited. In India, the 2023 amendment of the Biological Diversity Act changes the treatment of codified traditional knowledge in access and benefit-sharing (Cali Fund, 2026; Tiwari & Nandekar, 2025).
- Data: Census 2011 tabulated only 40 of the 75 PVTGs, and the national estimate of PVTG population rose from 28 lakh (2.8 million) to 44.71 lakh (4.47 million) within eight months (MoTA, 2016; Buddha & Mukkera, 2024).

KEYWORDS: CBD COP17; Article 8(j); Particularly Vulnerable Tribal Groups; habitat rights; Cali Fund; digital sequence information; traditional knowledge; India

INTRODUCTION

WHY THE YEREVAN MEETING MATTERS NOW

Four years after the adoption of the KMGBF, the CBD has moved from agreeing commitments to delivering them. Finance is expected to be the most contested item at COP17 (International Institute for Sustainable Development [IISD], 2026). At the seventh meeting of the Subsidiary Body on Implementation (SBI 7) in August 2026, it was reported that fewer than half of the Parties are on track to meet the framework's targets by 2030 (ENB, 2026). The Yerevan review is therefore the first formal stocktake of collective progress, and it falls at the halfway point of the framework's implementation (ENB, 2026). The agenda for Indigenous peoples and local communities (IPLCs) is substantial. COP17 will consider the operating rules (modus operandi) of the Subsidiary Body on Article 8(j), the implementation of the programme of work on Article 8(j) to 2030, an in-depth dialogue on Article 8(j), and the recommendations of the United Nations Permanent Forum on Indigenous Issues (SCBD, 2026a). In parallel, discussions on digital sequence information (DSI) and the Cali Fund will influence whether monetary benefits reach IPLCs (ENB, 2026).

Why PVTGs need a separate lens

India recognises 75 PVTGs in 18 States and the Union Territory of the Andaman and Nicobar Islands (MoTA, 2025). The PVTG category traces its policy lineage to the Dhebar Commission (1960–61), which drew attention to uneven levels of development among Scheduled Tribes; a distinct sub-category was subsequently created and was later renamed from Primitive Tribal Groups to Particularly Vulnerable Tribal Groups in 2006 (Scheduled Areas and Scheduled Tribes Commission, 1961; Scheduled Castes and Scheduled Tribes Research and Training Institute [SCSTRTI], 2015). They form a small subset of the Scheduled Tribe population, which constitutes about 8.6% of the national population (PIB, 2024). Official policy has historically identified PVTGs by a pre-agricultural level of technology, very low literacy, economic backwardness and a declining or stagnant population (MoTA, 2016). They largely live in small, scattered hamlets in remote areas (Buddha & Mukkera, 2024). Their habitats may overlap with forests and with the rights of other communities (MoTA, 2015). The global evidence base supports attention to such communities. Indigenous Peoples manage or hold tenure rights over at least 38 million km² of land in 87 countries (Garnett et al., 2018). A systematic review of 169 publications found that most cases with positive outcomes for both well-being and conservation involved IPLCs in a central role (Dawson et al., 2021). Across the tropics, deforestation was reduced in Indigenous Lands relative to non-protected areas, at a level comparable to that of protected areas and greater in Africa (Sze et al., 2022).

Indicator	Value	Source
Number of PVTGs	75, in 18 States and the Union Territory of the Andaman and Nicobar Islands	MoTA (2016, 2025)
Notified Scheduled Tribes	Over 730 Scheduled Tribes notified; about 8.6% of the national population	PIB (2024)
Census 2011 coverage of PVTGs	Population tabulated for 40 groups only (those notified as single-entry Scheduled Tribes)	MoTA (2016)
PM JANMAN outlay	INR 24,104 crore; mission period 2023–2026; 11 interventions through nine-line Ministries	PIB (2023); MoTA (2025)
Estimate at launch (November 2023)	Over 28 lakh people in 7.12 lakh households; 22,544 villages and habitations; 840 blocks in 220 districts	PIB (2023)

Scope and approach

This article draws on official CBD documents (the provisional agenda of COP17, subsidiary-body reports and the target texts of the KMGBF), parliamentary replies and communications of the Government of India, peer-reviewed studies, and independent reporting of the negotiations. Events after 15 October 2026 are not covered.

COP17 and the Indigenous agenda

The road to Yerevan

The KMGBF was adopted at COP15 in December 2022. COP16 in Cali (October–November 2024) established the Subsidiary Body on Article 8(j) and adopted Decision 16/2 on DSI. The resumed session in Rome (February 2025) launched the Cali Fund (ENB, 2025; SCBD, 2025b). The Subsidiary Body is a permanent body of the Convention dedicated to IPLC matters, and replaces the earlier working group (SCBD, 2025a). Its first meeting (SB8J-1) was held in Panama City from 27 to 30 October 2025 (SCBD, 2025a). SBSTTA 28 and SBI 7 met in Nairobi from 27 July to 12 August 2026 (ENB, 2026). Global reviews of collective progress are scheduled for COP17 (October 2026) and COP19 (October 2028) (ENB, 2025).



Figure 1. *The road to Yerevan: sequence of meetings of the Convention (ENB, 2025, 2026; SCBD, 2025a, 2025b).*

For PVTGs, the COP17 agenda converges around four linked questions: representation in Article 8(j) processes; recognition of territories and habitat rights; access to benefits from digital sequence information and the Cali Fund; and the data through which progress is made visible. These four issues provide the analytical structure used below.

FOUR ISSUES TO FLAG AT THE FORUM

Four aspects of the COP17 agenda are especially consequential for PVTGs in India: representation in Article 8(j) processes; recognition of territories and habitat rights; access to benefit-sharing mechanisms; and visibility in the data used for the first global review. Each raises a distinct question about whether a CBD commitment can be translated through India's legal and institutional framework to PVTG communities. The discussion below examines these concerns through the specific COP17 processes in which they arise.

REPRESENTATION AND TERMINOLOGY

Representation is the first concern because COP17 will consider the modus operandi of the Subsidiary Body on Article 8(j), including arrangements for the nomination and selection of IPLC representatives (SCBD, 2026a, 2026b). For PVTGs, this question is sharpened by marked demographic heterogeneity. Population size varies by several orders of magnitude. Census 2011 counts of single-entry PVTGs range from 15 (Sentinelese) to over 414,000 (Baiga in Madhya Pradesh alone) (MoTA, 2016; Figure 2). This spread supports the caution voiced in the CBD informal dialogue against treating IPLCs as a homogeneous group (SCBD, 2026b).

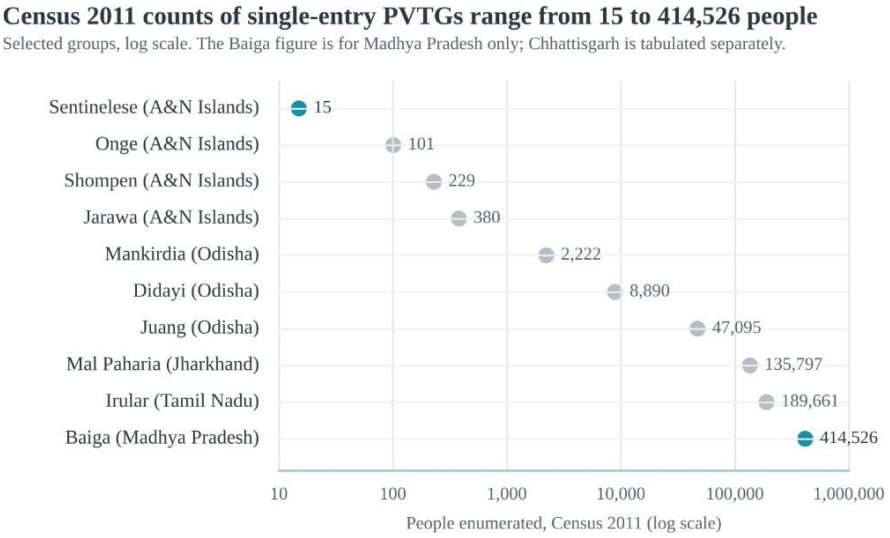


Figure 2. *Population of selected PVTGs scheduled as single-entry Scheduled Tribes, Census 2011 (MoTA, 2016).*

Target 22 of the KMGBF calls for full, equitable, inclusive, effective and gender-responsive representation and participation of IPLCs in decision-making, together with access to justice and information, while respecting their rights over lands, territories, resources and traditional knowledge (SCBD, n.d.-c). The Subsidiary Body on Article 8(j) is the principal institutional expression of this target within the Convention.

India's position complicates direct translation. India ratified ILO Convention 107 and voted in favour of the UN Declaration on the Rights of Indigenous Peoples, but has not ratified ILO Convention 169. The Government rejects equating Scheduled Tribes with Indigenous peoples,

while following the operational directives of multilateral agencies when projects are financed by them (IFAD, 2022). In CBD processes, the channels available to PVTG communities are therefore likely to be the national delegation and the global IPLC caucuses. The question to be raised at COP17 is whether the modus operandi, particularly its nomination and selection arrangements, can recognise this heterogeneity and create space for the concerns of numerically small communities within Article 8(j) deliberations.

TERRITORIES AND HABITAT RIGHTS

Territorial recognition is the second concern because COP17 work linked to Targets 2 and 3 addresses Indigenous and traditional territories, spatial planning and impact assessment. For PVTGs, the domestic counterpart of 'Indigenous and traditional territories' in Target 3 is the right to community tenure of habitat and habitation under Section 3(1)(e) of the Forest Rights Act, 2006 (MoTA, 2015; SCBD, n.d.-a). In 2015, the Ministry of Tribal Affairs observed that the Hindi text of the Act translated 'habitat' as a word commonly understood as house or homestead, and that several States had consequently equated habitat rights with housing schemes. The Ministry clarified that habitat rights may be recognised over customary territories used for habitation, livelihoods and social, economic, spiritual, sacred and religious purposes. It also directed that District Level Committees ensure that PVTGs receive habitat rights in consultation with their traditional institutions, and that the area of each claim be mapped (MoTA, 2015). Habitats may overlap with forests and with the rights of other communities (MoTA, 2015). A documented example of the process is the recognition of habitat rights of the Kamar PVTG in Dhamtari district, Chhattisgarh (UNDP India, 2023).

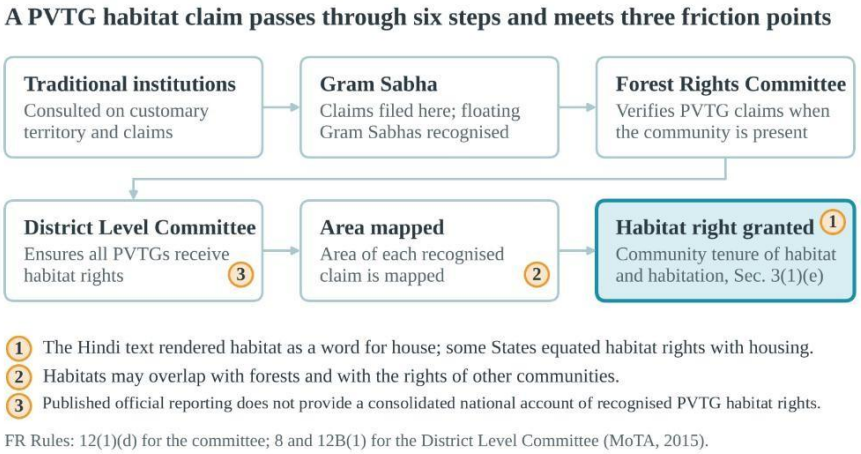


Figure 3. *Route of a PVTG habitat-right claim under the Forest Rights Act, 2006, and friction points (MoTA, 2015; point 3 reflects the national reporting gap discussed in Section 4.2).*

The Government's flagship PVTG programme, PM JANMAN, concentrates on housing, roads, water, health services and similar amenities (PIB, 2023). These interventions address critical infrastructure and service deficits, but they do not themselves constitute legal recognition of habitat under Section 3(1)(e) of the Forest Rights Act (MoTA, 2015; PIB, 2023). The question to be raised at COP17 is whether work under Targets 2 and 3 treats the recognition and mapping of customary territory, and the conditions under which conservation measures overlap PVTG habitats, as measurable implementation concerns (ENB, 2025; SCBD, n.d.-a).

BENEFIT-SHARING: DSI, THE CALI FUND AND DOMESTIC LAW

Benefit-sharing is the third concern because COP17 will consider the Cali Fund allocation methodology while implementation of Target 13 and Article 8(j) continues to define how benefits from DSI and traditional knowledge are to be shared. For PVTGs, the relevant question is not only whether benefits are earmarked for IPLCs, but whether a practical route exists through which small communities can access them. Target 13 addresses benefit-sharing from genetic resources, DSI and traditional knowledge associated with genetic resources. Article 8(j) separately encourages the equitable sharing of benefits from the use of the knowledge, innovations and practices of IPLCs (SCBD, n.d.-b).

The Cali Fund operationalises the DSI strand. Contributions are expected from large enterprises that meet size criteria, which include annual sales or revenue of at least USD 50 million among other thresholds (SCBD, n.d.-d). The Fund is also meant to support the self-identified needs of IPLCs, including women and youth (SCBD, n.d.-d). By 15 October 2026, three companies had made contributions to the Fund, but the scale of private-sector participation remained limited (Cali Fund, 2026).

The allocation methodology for disbursement is before COP17 for consideration (SCBD, 2026c).

The Biological Diversity (Amendment) Act, 2023 excludes codified traditional knowledge, for Indians, from the definition of 'benefit claimers' and exempts access to codified traditional knowledge from the prior-intimation requirement under Section 7. The amendment also exempts specified local people and communities, vaids, hakims and registered AYUSH practitioners under that section. Its implications for custodian communities and benefit-sharing have been raised as a concern (Tiwari & Nandekar, 2025). The question to be raised at COP17 is whether the Cali Fund allocation methodology and related implementation arrangements provide a workable access route for communities of PVTG scale, while remaining coherent with domestic benefit-sharing rules (SCBD, 2026c; SCBD, n.d.-b).

DATA VISIBILITY AND INDICATORS

Data visibility is different from the preceding three issues because it determines whether progress on representation, tenure and benefit-sharing can be demonstrated at all. This is particularly important at COP17, which will undertake the first global review of the KMGBF and draw on advice concerning traditional knowledge and IPLC participation (ENB, 2025, 2026). Delegates at SBI 7 called for stronger inclusion of IPLCs and recognition of traditional knowledge in the draft review (ENB, 2026). What counts in the review depends on what is measured. For PVTGs, three layers of data are weak.

National estimates of PVTG population are unstable. The Census enumerates notified Scheduled Tribes separately and does not collect specific data on PVTGs as a category (Buddha & Mukkera, 2024). Under PM JANMAN, the estimate rose from about 28 lakhs at launch to 44.71 lakh within eight months. The estimates were drawn from the PM Gati Shakti portal, which identified habitations and estimated households instead of conducting a household survey (Buddha & Mukkera, 2024).

Date	Estimated PVTG population	Remark
November 2023	About 28 lakh (2.8 million)	Estimate at launch of PM JANMAN
Mid-January 2024	36.75 lakh (3.675 million)	First upward revision
July 2024	44.71 lakh (4.471 million)	About 60% above the launch estimate; housing targets were not revised in the Interim Budget (February 2024) or the 2024-25 Union Budget

Source: Buddha and Mukkera (2024).

Central and State figures also diverged. For Jharkhand, the Ministry identified 3,500 PVTG households against 70,000 reported by the State, and the national habitation count was revised from 22,000 to 30,000 by March 2024 (Buddha & Mukkera, 2024). Planning and benefit design therefore rest on counts that remain uncertain.

Reliability: Anomalies exist in historical series. The Jenu Kuruba count rose from 6,623 in 1971 to 34,747 in 1981, and a possible explanation offered in the literature is that other groups claimed the identity (Buddha & Mukkera, 2024, citing Misra, 2016).

Participation: Gram sabhas are well placed to collect accurate data, yet field observations indicate that they were not consulted in the PM JANMAN estimation (Buddha & Mukkera, 2024).

Existing national-level reporting on PVTGs provides limited systematic information on traditional knowledge and linguistic diversity. Linguistic and biological diversity show strong geographic concordance in biodiversity hotspots, which has been interpreted as pointing to a functional connection (Gorenflo et al., 2012). Whether the loss of a small language carries ecological information with it is a hypothesis that requires testing at PVTG level. The question to be raised in the global review is therefore whether indicators can be disaggregated far enough to make PVTG-level changes in participation, territorial recognition, benefit access and traditional knowledge visible.

KEY POLICY, EVIDENCE AND IMPLEMENTATION GAPS

Taken together, the four issues reveal a common problem: CBD commitments can be articulated at global level while the institutional and evidentiary conditions needed to translate them for PVTGs remain incomplete. The first three gaps concern the pathways through which

PVTGs can be represented, secure territorial recognition and access benefits. The fourth concerns the information needed to make all three pathways visible and measurable. Data is therefore not an additional issue alongside the others; it is the evidentiary layer on which representation, tenure and benefit-sharing are planned, monitored and reported.

Representation gap

Existing policy and institutional literature does not identify a dedicated representation pathway through which numerically small PVTGs can participate directly in CBD processes. The nomination and selection arrangements of the Subsidiary Body on Article 8(j) therefore remain especially important for ensuring that heterogeneity within the wider IPLC constituency is recognised.

Tenure and reporting gap

Published official reporting does not provide a consolidated national account of PVTG habitat-right claims filed, recognised and mapped under Section 3(1)(e) of the Forest Rights Act. This limits the use of habitat-right recognition as a measurable national indicator for Target 3.

Benefit-sharing gap

Current Cali Fund guidance provides for support to IPLCs through government channels or self-selected entities, but the allocation methodology is still before COP17. How groups of PVTG scale would practically access the IPLC share of the Fund remains insufficiently specified. At the domestic level, the treatment of codified traditional knowledge under the 2023 amendment also requires clarification in relation to benefit-sharing with custodian communities.

Data and knowledge gap

Data weakness compounds each of the preceding gaps. PVTG enumeration remains incomplete and unstable, while existing national-level reporting provides limited disaggregated information on traditional knowledge, customary territories and language. Without such information, it is difficult to identify who is represented, which territories and rights have been recognised, who receives benefits, and whether outcomes are visible in the global review. The data and knowledge gap is therefore not simply an additional reporting problem; it is the evidentiary constraint running across representation, tenure and benefit-sharing.

A model of the governance cascade

The four gaps identified above do not operate independently. A decision taken at a COP pass through several layers before it affects a hamlet. Figure 4 summarises this cascade for PVTGs and shows how representation, tenure and benefit-sharing can be interrupted at different points, while weak data can obscure outcomes across all of them. The model is an analytical synthesis of the sources cited in this article. It is offered to guide the formulation of interventions at COP17 and is not an empirical estimate.

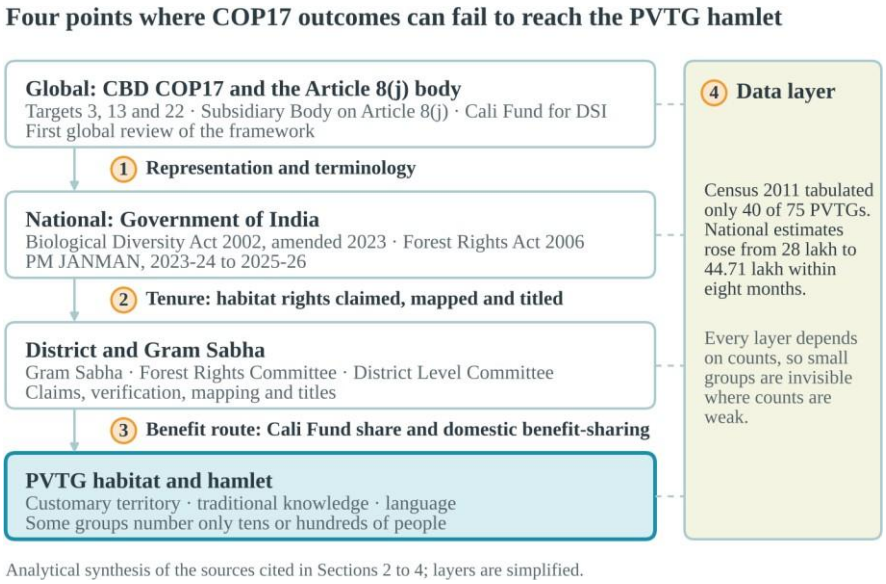


Figure 4. *The governance cascade from treaty decision to PVTG hamlet. Numbered markers show where outcomes can fail to arrive.*

Implication for the global review

A review that measures progress only at the first two layers, treaty decisions and national law, will register delivery that has not reached the hamlet. The cascade therefore suggests a simple test for COP17

outcomes: each decision should specify the layer at which its effect will be verified, and at least one indicator should be measurable at the level of the community.

RECOMMENDATIONS

The recommendations are grouped by the four issues and are addressed to the actors who hold the decision.

Issue	Recommendation	Addressed to
Representation	Recognise heterogeneity within the IPLC constituency in the modus operandi of the Subsidiary Body, including its nomination and selection criteria	COP17 Parties; Subsidiary Body on Article 8(j)
Representation	Hold consultations with PVTG traditional institutions before national positions on Article 8(j) are set	Government of India; State tribal welfare departments
Tenure	Name recognition of customary territory, and free, prior and informed consent, as measurable elements of the guidelines for Targets 2 and 3	Subsidiary Body on Article 8(j); COP17
Tenure	Report PVTG habitat-right claims filed, recognised and mapped, State by State, in national reporting	Ministry of Tribal Affairs; State governments
Benefit-sharing	Specify a clear access route for small, forest-dependent groups to the IPLC share of the Cali Fund in the allocation and disbursement arrangements	Cali Fund governance; COP17 Parties
Benefit-sharing	Clarify how codified traditional knowledge is treated under the 2023 amendment in relation to benefit-sharing with custodian communities	Ministry of Environment, Forest and Climate Change; National Biodiversity Authority
Data	Adopt traditional-knowledge, territory and language indicators that can be disaggregated for small groups in the global review	COP17 Parties; Subsidiary Body on Implementation
Data	Undertake a PVTG-specific enumeration led together with gram sabhas, so that planning rests on verified counts	Ministry of Tribal Affairs; Registrar General of India

CONCLUSION

The Yerevan agenda contains real gains for IPLCs: a permanent Subsidiary Body, explicit provisions on traditional territories, and a benefit-sharing fund with half of its resources earmarked for IPLC needs. For India's 75 PVTGs, each gain meets a filter before it reaches the hamlet. Representation is shaped by terminology, tenure by the slow and poorly documented recognition of habitat rights, benefit-sharing by limited private-sector contributions and an unsettled allocation pathway alongside a loosened domestic regime, and visibility by population data that remain unstable. The central inference is that the success of COP17 for the smallest communities should be judged at community level and not only at the level of decisions adopted. PVTGs provide a stringent test of whether the CBD's IPLC commitments translate into community-level outcomes.

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Science of Sustainability



Beyond Carbon: Climate Mitigation, Mangrove Restoration and Community Governance in the Bay of Bengal – A Critical Review

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Abstract

Mangrove restoration is increasingly promoted as a means of storing carbon while protecting exposed coastlines. Yet the expansion of planted areas does not necessarily demonstrate ecological recovery, additional climate benefits or equitable local outcomes. This critical review examines those distinctions using official mangrove-cover statistics for India and published field studies conducted in the Sundarban across the Indian and Bangladeshi territories. Findings indicate that area-based targets and seedling counts are insufficient measures of restoration performance. Credible programmes require sustained ecological monitoring, cautious carbon accounting and meaningful participation in management decisions. Mangrove protection can support climate mitigation alongside adaptation, but cannot replace direct cuts in emissions from fossil fuels.

Keywords: blue carbon; coastal wetlands; ecological restoration; Sundarban; climate mitigation; community governance; Bay of Bengal

Introduction

Mangroves occupy a limited portion of global coastlines, yet their ecological importance extends far beyond stored carbon (Ashrafuzzaman, 2025). Their vegetation and sediments retain organic carbon, while their root systems influence sediment movement, support aquatic food webs and moderate some forms of coastal flooding (Cahoon et al., 2021). These attributes have encouraged the inclusion of mangrove protection and rehabilitation within climate policy and coastal disaster preparedness. The challenge is to determine what these interventions actually deliver. A planted shoreline may gain tree cover without recovering the ecological processes of an established mangrove forest; likewise, an observed increase in carbon stock does not, by itself, establish additional and lasting reductions in atmospheric greenhouse gases.

These distinctions matter in the Bay of Bengal, where mangrove habitats coexist with densely inhabited coasts, changing salinity, erosion, aquaculture, fishing and contested access to natural resources (Bhattacharya et al., 2026). The transboundary Sundarban offer a particularly useful setting for examining whether restoration initiatives meet both ecological and social objectives. The central question of this review is therefore: under which ecological and governance conditions can mangrove protection and rehabilitation deliver measurable climatic benefits alongside livelihood security and habitat recovery?

Three propositions guide the discussion. First, changes in mapped mangrove extent cannot be taken as direct evidence of improved carbon sequestration. Second, recovery depends on habitat conditions and sustained management rather than planting activity alone. Third, community participation must be assessed through influence over decisions and distribution of benefits, not merely through attendance or labour contributions.

Scope and Approach

This article presents a focussed critical synthesis rather than a systematic review or a report of original fieldwork. Its evidence comprises the Forest Survey of India's national assessment, empirical restoration investigations in the Indian Sundarban, participatory and fisheries-governance studies from the wider delta, and scholarship addressing blue-carbon accounting, coastal protection and the persistence of carbon storage. Studies were chosen for their direct relevance to the three propositions and for reporting identifiable methods or quantitative findings. Their

measurements are retained in their original units and interpreted within their specific geographic and methodological contexts.

Nationwide satellite classifications, carbon stocks measured in field plots, plantation survival, participatory spatial records and simulated protection from flooding represent distinct types of evidence. They are therefore interpreted within their original study boundaries; this review does not aggregate them into a regional estimate or infer causal effects from their juxtaposition. No new primary observations, field measurements or statistical tests were undertaken for this review.

WHAT INDIA'S MANGROVE-COVER STATISTICS ESTABLISH-AND WHAT THEY DO NOT

The Forest Survey of India (2024) reported 4,991.68 km² of mangrove cover for the 2023 assessment. Of this, 1,463.97 km² was classified as very dense, 1,500.84 km² as moderately dense and 2,026.87 km² as open mangrove. Open mangroves therefore represented 40.60% of the reported extent. Relative to the revised assessment for 2021, the national total fell by 7.43 km². The national change masks divergent state trajectories: Andhra Pradesh and Maharashtra gained mapped mangrove cover, while Gujarat experienced a substantial decline. For 2023, the corresponding state totals were 2,119.16 km² in West Bengal and 259.06 km² in Odisha (Forest Survey of India, 2024).

West Bengal and Odisha are highlighted because both border the Bay of Bengal and contain ecologically important but geographically distinct mangrove settings: the Indian Sundarban in West Bengal, and Bhitarkanika together with the Mahanadi-delta systems in Odisha (Ministry of Environment, Forest and Climate Change, 2023). Their figures provide a regional frame for the discussion. However, the detailed field studies considered below are predominantly from the Sundarban.

Table 1. Selected indicators from the India State of Forest Report 2023

Indicator	Reported value	Relevance to restoration assessment
Total Indian mangrove cover, 2023	4,991.68 km²	National extent at the assessment date
Very dense mangrove	1,463.97 km² (29.33%)	Canopy-density class, not a carbon-stock measurement
Moderately dense mangrove	1,500.84 km² (30.07%)	Canopy-density class, not proof of ecosystem condition
Open mangrove	2,026.87 km² (40.60%)	Large proportion warrants attention to stand structure
Net national change, revised 2021–2023	−7.43 km²	Change in mapped area, not a measured carbon flux
West Bengal cover, 2023	2,119.16 km²	Extent associated with the Indian Sundarban landscape
Odisha cover, 2023	259.06 km²	Extent across Bhitarkanika and other Odisha coastal landscapes

Source: Forest Survey of India (2024), India State of Forest Report 2023. Values are official published estimates, rearranged for interpretation; no new measurements were made.

The official data help locate broad spatial differences, although canopy-density categories cannot establish soil carbon, forest age, species composition, sediment stability or ecological connectivity. Similarly, a national net-area figure cannot tell whether a site has developed into a functioning forest or merely acquired recently planted trees. Moreover, a nearly unchanged national total can conceal sizeable local gains and losses.

Improved monitoring would combine mapped extent and canopy class with recurring on-site assessments of tidal exchange, spontaneous recruitment, habitat condition and carbon reservoirs. The emphasis

should be on what is being restored, not simply how much land is labelled as mangrove.

Restoration outcomes in the Indian Sundarban

Site-based investigations reveal the limitations of judging success through planting effort or the hectares planted. Chowdhury et al. (2025) compared three experimental sites of approximately one hectare each in the Indian Sundarban. At the first location, community protection lasted one year; at the second, organised local involvement continued for two years. The third location received no organised protection after planting. Following planting in 2012, the researchers assessed outcomes in 2017. For *Rhizophora mucronata*, recorded survival was 2% at the one-year participation site, 71% at the two-year site and 0% at the unprotected site. For *Sonneratia caseolaris*, corresponding survival rates were 4%, 40% and 0%. At the site with longer protection, the reported soil blue-carbon stock was 64.4 Mg C ha^{-1} initially and 88.6 Mg C ha^{-1} at follow-up.

These contrasts suggest that prolonged local protection may contribute to better survival and improved sediment conditions. They do not, however, isolate community engagement as the sole causal explanation. The study involved only three plots, and site-specific environmental conditions may also have influenced outcomes. Moreover, the published stock measurements reflect conditions within one small study area; they cannot legitimately be multiplied across the Sundarban to estimate regional carbon gains. The paper also contains an apparent mismatch between its two reported stock values and its stated percentage increase; this review therefore retains the published absolute measurements without reproducing that percentage.

A separate investigation evaluated recovery against local ecological reference conditions. Ray et al. (2024) tested site-sensitive rehabilitation at 31 degraded coastal patches in the Indian Sundarban, spanning approximately 65 ha. The researchers adapted species choice, planting configuration and associated interventions to the characteristics of each location. Detailed evaluation at the Ramganga site indicated that naturally recruiting mangrove seedling richness rose from approximately four to five species in 2014 to 12–14 in 2022. For comparison, the investigators reported 15–18 species at relatively undisturbed reference sites and only two to three in local monospecific plantations. They also reported a substantial increase in the density of naturally established seedlings over the monitoring period.

This distinction is important: self-recruiting seedlings suggest that ecological regeneration is underway, whereas the continued presence of planted trees establishes only their survival. Nevertheless, Ramganga remained below reference levels for some measures. Calling such a habitat fully restored would overlook the time needed for ecological functions to recover. Taken together, these two studies support a shift from counting seedlings at planting to tracking species composition, regeneration and habitat function over several years.

Carbon accounting: stocks, additionality and permanence

A defensible climate claim requires comparison between the intervention and a plausible no-project trajectory. A carbon stock measures the quantity held in vegetation or soil at a given point in time. Sequestration rates refer to accumulation over time. Avoided emissions refer to greenhouse gases that would otherwise have entered the atmosphere. These quantities must not be treated as interchangeable when reporting progress in meeting net-zero commitments.

Research on coastal blue-carbon habitats estimates substantial mitigation opportunities from protection and rehabilitation, but the range of estimates depends on assumptions about restoration feasibility, emissions avoidance and land-use change (Macreadie et al., 2021). Jones et al. (2024) identify three tests that are particularly relevant to project-level claims: additionality, feasibility and permanence. A restoration site that would have regenerated naturally may deliver fewer additional gains than a heavily degraded site. An area subject to continuing erosion or hydrological disruption may not retain newly stored carbon. Restoration can also alter methane emissions and carbon transfers beyond the

immediate project boundary, complicating the net greenhouse-gas balance.

Longer-term climatic threats further weaken the assumption that every planted stand offers secure carbon storage. Wu et al. (2026), using global mangrove biomass modelling under different climate scenarios, projected a 19.3% decline in above-ground biomass by 2100 under a high-warming pathway, despite management and restoration possibilities. This is a global scenario result, not a forecast for a particular Sundarban locality. It nevertheless demonstrates why future sea-level rise and the availability of space for landward habitat migration matter for carbon permanence.

For the Bay of Bengal, a defensible carbon-monitoring programme would therefore require a documented baseline, repeat observations of vegetation and soil carbon, an explicit counterfactual, and assessment of erosion, salinity and land-use pressures. Estimated carbon gains should be reported alongside the uncertainty arising from sampling depth, seasonal variation and the duration of monitoring. Blue-carbon initiatives can complement climate policy, but they must not be presented as a justification for continued emissions from fossil fuels.

Coastal protection is important, but not universal

Carbon alone offers a narrow basis for prioritising mangrove investments. Menéndez et al. (2020) modelled global coastal flooding with and without existing mangrove forests. Their analysis estimated annual avoided flood damage exceeding US$65 billion and found that, without mangroves, approximately 15 million additional people would experience flooding each year. The model identified substantial populations protected along the coasts of both India and neighbouring Bangladesh. These are model-based global results, not observed annual savings or monetary estimates for a particular project in the Sundarban.

Protection depends on the width and condition of the mangrove belt, shoreline geometry, elevation, storm characteristics and the location of settlements or infrastructure. It would consequently be mistaken to presume that any short mangrove plantation can reproduce the protective function of an established coastal forest. Equally, measures such as embankment management, safer housing and evacuation systems will still be needed in many locations. The policy implication is not to diminish the value of mangroves, but to assess coastal protection as a place-specific service rather than a guaranteed outcome of planting.

Community stewardship and the problem of representation

The argument for community-led restoration is stronger when local people influence site selection, management rules and benefit distribution. Otherwise, participation may amount to providing labour while decisions remain external. Evidence from the Bangladeshi Sundarban shows why livelihood distinctions cannot be overlooked. Polas et al. (2025) consulted 251 people engaged in forestry-related livelihoods, tertiary services, agriculture and aquaculture. Using participatory spatial mapping, the researchers documented 1,297 geolocated perceptions concerning ecosystem damage and potential recovery measures. The resulting maps showed differences in the pressures and interventions emphasised by the various groups. This is evidence that local priorities are spatially and socially differentiated; it does not mean that every mapped location represents an independently verified degradation event.

Recent research on small-scale fisheries in the transboundary Sundarban adds an institutional concern. Miah et al. (2026) reported that 78% of the fishers surveyed in the Bangladesh component were unaware of existing co-management initiatives. Their wider findings identified limited influence over governing arrangements and livelihood restrictions among the difficulties facing fishing communities. This survey statistic concerns the study respondents and cannot be generalised to the entire population around the Sundarban.

Together, the studies indicate that community involvement has several distinguishable dimensions: contribution to planting and maintenance, recognition of local ecological knowledge, representation in decisions, and access to resulting benefits. A project can perform well on the first dimension while falling short on the others. Community governance should therefore be evaluated through transparent decision-making, arrangements for customary resource use, conflict resolution and the distribution of costs as well as benefits. The treatment of fishers, women and households dependent on intertidal resources is especially important where conservation rules alter access to livelihood areas.

Implications for Restoration Policy and Monitoring

India's Mangrove Initiative for Shoreline Habitats & Tangible Incomes (MISHTI), launched in June 2023, provides a policy setting in which the distinction between planting targets and ecosystem outcomes has practical relevance (Ministry of Environment, Forest and Climate Change, 2025). Based on the evidence examined here, programme evaluations should move beyond area planted and number of saplings distributed.

An effective framework would track four related forms of performance. Ecological recovery requires information on species diversity, survival beyond the initial planting period, naturally recruiting seedlings, hydrological connectivity and sediment condition. Climate performance requires repeated carbon measurements, a defensible no-intervention baseline and explicit treatment of permanence risks. Protective function should be examined in relation to local coastal topography, actual exposure and the wider disaster-risk system. Social outcomes should document who participates in decisions, who gains access to benefits, whose resource use is restricted and whether restoration improves livelihood security.

The order of intervention is also important. Sites with functioning tidal exchange and adequate natural propagule supply may be more suitable for protection or assisted natural regeneration than for intensive planting. Where hydrology is disturbed, correcting physical conditions may be necessary before seedlings can establish. Initial planting success alone cannot justify crediting a project with lasting carbon gains or sustained protection without follow-up verification. Independent monitoring and public reporting of unsuccessful as well as successful sites would make future investment choices more defensible.

Conclusion

The evidence does not support treating mangrove planting, rising canopy cover and climate mitigation as equivalent achievements. India's official cover assessment identifies the scale and distribution of mangrove habitat but does not measure its complete ecological or carbon condition. Studies in the Sundarban show that restoration outcomes differ markedly with site management, ecological design and the duration of protection, while research with coastal communities exposes the limitations of participation that does not translate into decision-making authority.

Protecting mangroves helps retain stored carbon, provides opportunities for habitat regeneration and may lessen specific coastal hazards. Any claimed role in achieving net-zero emissions remains conditional and must be accompanied by a clear statement of uncertainty. For the Bay of Bengal, the sounder objective is sustained recovery of functioning coastal ecosystems, rather than maximising seedling numbers, with governance arrangements that are ecologically appropriate and socially accountable.

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Review article

Beyond the Northern Bay of Bengal: A Review of Horseshoe Crab (Tachypleus gigas and Carcinoscorpius rotundicauda) Records, Status and Evidence Gaps in Central–Southern Odisha and India's Other Coastal States

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Abstract

Background: Two horseshoe crab species, *Tachypleus gigas* and *Carcinoscorpius rotundicauda*, are recorded from India. Published research is concentrated in West Bengal and northern Odisha. The status of both species along the rest of the Indian coastline has not been synthesised.
Methods: A systematic search of open bibliographic indexes, publisher platforms and official repositories was conducted in October 2026, following the principles of the PRISMA 2020 statement. Sources published from 2021 onwards were preferred; older sources were retained only where no recent source covered the same region or question. Evidence was graded by region and by evidence type.
Results: Eleven sources were included in the synthesis. No occurrence record of either species was located for Tamil Nadu, Puducherry, Kerala, Karnataka, Goa, Maharashtra, Gujarat or Lakshadweep. For the Andaman and Nicobar Islands, only an unsupported mention in a news report was found. In southern Odisha, *T. gigas* was recorded at depths of 20-30 m off Chilika and Gopalpur without eggs or juveniles, and the only density estimate (15-20 individuals km^{-1} season^{-1}) dates from 2005-2007. In Andhra Pradesh, *T. gigas* was recorded up to Visakhapatnam, at about 10 individuals km^{-1}, without evidence of breeding; *C. rotundicauda* has not been recorded from the state. Both species are listed in Schedule II of the Wild Life (Protection) Act, 1972, as amended in 2022. Their IUCN Red List assessments (Data Deficient) date from 1996, and reassessment is in progress.
Conclusions: The documented southern limit of *T. gigas* in India lies on the northern Andhra Pradesh coast, and breeding has been documented only as far south as the Devi estuary. The available evidence cannot separate a true range limit from an absence of survey effort. Repeat surveys in southern Odisha and Andhra Pradesh, presence–absence surveys elsewhere, and genetic sampling at the range margin are identified as priorities.

Keywords: horseshoe crab; *Tachypleus gigas*; *Carcinoscorpius rotundicauda*; range margin; southern Odisha; Andhra Pradesh; Schedule II; Data Deficient; systematic review

Introduction

Horseshoe crabs in the Indo-Pacific

Four horseshoe crab species are extant, and three of them occur in Asia, where their range extends from the Bay of Bengal in India to southern Japan (Botton et al., 2022). Asian populations are exposed to the loss and degradation of spawning and nursery habitats, entanglement in fishing gear, harvest for food, bait and traditional medicine, and bleeding for amebocyte lysate (Botton et al., 2022). For India, the principal threats have been ranked as the loss of spawning and nursery habitat, bycatch, and use in traditional medicine (Botton et al., 2022).
Species distribution modelling has hypothesised that *T. gigas* occupies a distinct distribution area extending from India to South Viet Nam, and has projected that the Bay of Bengal will become less suitable for the species by 2050 (Vestbo et al., 2018). The same study modelled suitable habitat for *C. rotundicauda* extending from the Bay of Bengal, including Sri Lanka, to southern China (Vestbo et al., 2018). The western edge of the Asian range, and therefore the Indian coastline, is of particular interest. Populations at the edge of a range are those in which a climate-driven contraction would first be detected, and their location defines the extent of occurrence used in status assessments.

The Indian context

Two species are recorded from India: the Indo-Pacific or coastal horseshoe crab, *T. gigas* (Müller, 1785), and the mangrove horseshoe crab,

C. rotundicauda (Latreille, 1802) (Raghunathan & Mondal, 2024). Indian research has focused on the coasts of West Bengal and northern Odisha since studies of spawning migration in the Budhabalanga estuary in the 1980s (Chatterji et al., 1992), and population, morphometric and conservation studies continue there (Pramanik et al., 2021; Shaik et al., 2024; Panda et al., 2025). A 2021 review of 56 sources described both species as restricted to north-eastern India, in Odisha and West Bengal (Pramanik et al., 2021). Whether this description reflects the distribution of the species or the concentration of research effort has not been examined.

AIM AND RESEARCH QUESTIONS

The present review was undertaken to synthesise the evidence on horseshoe crabs along the Indian coastline outside West Bengal and northern Odisha. Three research questions (RQ) were addressed:
RQ1. In which coastal states and union territories outside West Bengal and northern Odisha have horseshoe crabs been recorded, and with what strength of evidence?
RQ2. What is known of their occurrence, breeding, abundance and threats in central and southern Odisha and in Andhra Pradesh?
RQ3. What is their current legal and Red List status, and which evidence gaps limit status assessment at the national scale?

METHODS

REVIEW FRAMEWORK

The review was designed and reported following the principles of the PRISMA 2020 statement (Page et al., 2021). The evidence consisted largely of descriptive field records, checklists, reviews and official documents with heterogeneous methods and units. A narrative synthesis with structured evidence grading was therefore adopted in place of meta-analysis. No protocol was registered in advance.

STUDY AREA

The coastline was divided into eight target units: (i) central Odisha, from the Mahanadi mouth near Paradip, including Hukitola, to the Devi estuary; (ii) southern Odisha, from the Devi estuary to the Andhra Pradesh border, including the outer channel of Chilika Lagoon and the Ganjam coast; (iii) Andhra Pradesh; (iv) Tamil Nadu and Puducherry; (v) Kerala, Karnataka and Goa; (vi) Maharashtra and Gujarat; (vii) the Andaman and Nicobar Islands; and (viii) Lakshadweep. West Bengal and the northern Odisha coast (Balasore, Bhadrak and Kendrapara) were excluded, because the evidence base there is comparatively well developed. Where a source applied its own regional division, that division was retained and is stated in the text.

RECENCY RULE

Sources published from 2021 to 2026 were preferred. A source published before 2021 was retained only where no source from 2021 onwards reported the same data for the same region, or where it was the primary record of a legal or Red List status.

SEARCH STRATEGY

Searches were conducted in October 2026 through open web indexes and through publisher and repository platforms, including SpringerLink, Wiley Online Library, Frontiers, the Directory of Open Access Journals, ResearchGate, the Biodiversity Heritage Library, Research Square, the IUCN document library, the UNEP Law and Environment Assistance Platform and the document repository of the Zoological Survey of India (ZSI). Forty-two query strings were run, each combining a taxon block with a geographic block, a status block or both (Table 1). Reference lists of included sources were examined for further records.

Table 1. Components of the search strings and eligibility criteria.

Component	Terms and criteria
Taxon block	horseshoe crab; king crab; Xiphosura; Merostomata; *Tachypleus gigas*; *Carcinoscorpius rotundicauda*
Geographic block	Odisha (Paradip, Puri, Devi, Chilika, Gopalpur, Ganjam, Rushikulya); Andhra Pradesh (Srikakulam, Visakhapatnam, Kakinada, Godavari, Coringa, Krishna, Nellore); Tamil Nadu (Pulicat, Pichavaram, Palk Bay, Gulf of Mannar); Puducherry; Kerala; Karnataka; Goa; Maharashtra; Gujarat (Gulf of Khambhat, Gulf of Kachchh); Andaman and Nicobar Islands; Lakshadweep; Bay of Bengal; Sri Lanka

Status block	distribution; record; abundance; spawning; DNA barcoding; IUCN Red List; reassessment; Wild Life (Protection) Act; Amendment Act 2022; Schedule II
Inclusion	Field records, checklists, reviews or official documents reporting occurrence, breeding, abundance, threats, trade, genetics, legal status or Red List status of either species in a target unit, or national status; English language; traceable bibliographic details
Grey literature	Included only where it supplied a specific statement not available in peer-reviewed or official sources; reported with attribution and graded as low certainty
Exclusion	Data confined to West Bengal or northern Odisha; other taxa; studies outside India; sources without retrievable text; unattributed or unverifiable claims

SCREENING, DATA EXTRACTION AND EVIDENCE GRADING

Titles and search snippets were screened first. Records that passed this stage were assessed through their full text or complete abstract. The following data were extracted: target unit, species, study period, design, record type (adult, nest, egg or juvenile), density, threats or trade, genetic data, and legal and Red List status. Each extracted value was checked a second time against its source before synthesis. Screening and extraction were carried out by a single reviewer, which is acknowledged as a limitation (Section 4.4).

Evidence for each target unit was graded for five evidence types (occurrence, breeding, abundance, threat or trade, and genetic data) on a three-point scale. Level 2 was assigned to peer-reviewed or official evidence specific to the unit.Level 1 was assigned to indirect evidence, evidence pooled with other units, or grey literature. Level 0 was assigned where no evidence was located.

RESULTS

SEARCH OUTCOME

The 42 queries returned approximately 420 hits. After screening of titles and snippets, 47 records were sought for retrieval. Nine could not be retrieved in full (Section 4.4). Of the 38 records assessed, 27 were excluded: seven contained data confined to West Bengal or northern Odisha, five concerned other taxa or species, four concerned other countries, four contained no India-specific data, and seven were secondary, duplicate, truncated or unverifiable web items. Eleven sources were included: nine peer-reviewed or official sources and two news reports (Figure 1). Two IUCN Red List assessment records were also cited for the formal status of the species. The Red List pages could not be opened during the search; their identifiers were traced through secondary listings, and the current category was confirmed against the 2024–2025 report of the IUCN SSC Horseshoe Crab Specialist Group (2025).

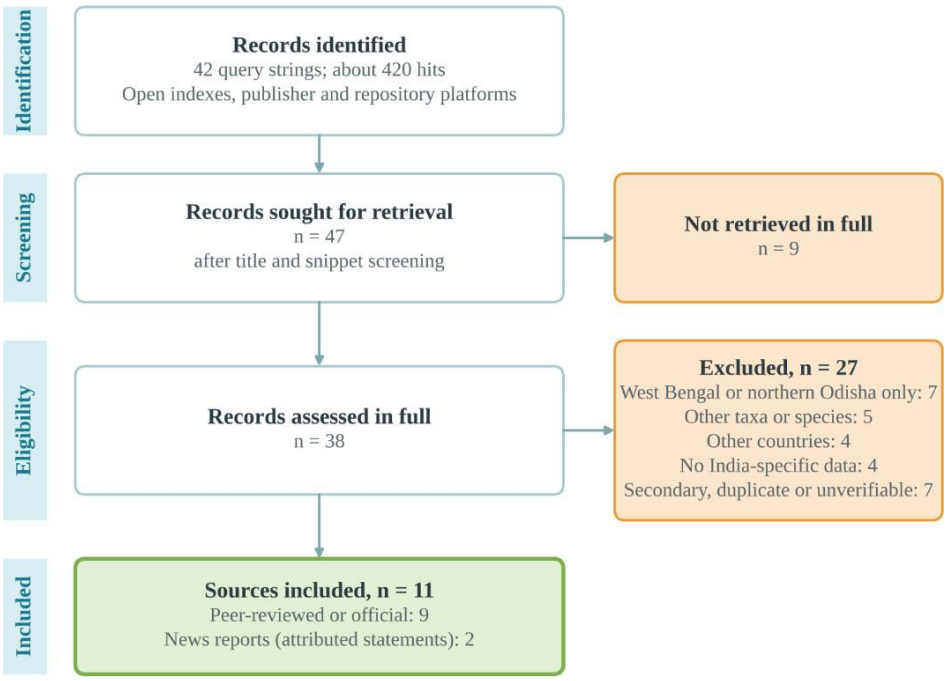


Figure 1. Flow of records through identification, screening, eligibility and inclusion, following the principles of the PRISMA 2020 statement (Page et al., 2021). The number of hits at identification is approximate.

Characteristics of the included sources

The included sources are listed in Table 2. Six were published from 2021 onwards: a national checklist (Raghunathan & Mondal, 2024), a national review (Pramanik et al., 2021), a global review chapter (Botton et al., 2022), a Specialist Group report (IUCN SSC Horseshoe Crab Specialist Group, 2025), the official record of the 2022 amendment to the Wild Life (Protection) Act (Wild Life [Protection] Amendment Act, 2022), and one news report (Mohanty, 2023). No primary field study from 2021 onwards was located for any target unit. Field data for the target units were therefore drawn from two older sources, Mishra (2009) and Tripathy et al. (2013), which remain the only primary field records for central–southern Odisha and Andhra Pradesh. The only population-genetic study that could be retrieved, Periasamy et al. (2017), and the only distribution-modelling study, Vestbo et al. (2018), were retained under the recency rule.

Table 2. Sources included in the synthesis.

Source	Type	Coverage	Data used in this review
Mishra (2009)	Book chapter; field records 1988–2007	Odisha and northern Andhra Pradesh	Species, habitat and depth, and presence of nests, eggs or juveniles by locality
Tripathy et al. (2013)	Book chapter; field survey December 2005 to June 2007	Odisha and adjoining coasts of West Bengal and Andhra Pradesh	Density by coastal sub-region; stranding mortality
Periasamy et al. (2017)	Journal article; COI sequencing	Indian east coast (sites not named in the accessible text)	Genetic differentiation and gene flow
Vestbo et al. (2018)	Journal article; distribution modelling	Asian range	Modelled suitable habitat; 2050 projection
Ghosh (2019)	News report	Odisha, West Bengal, Andhra Pradesh	Range statement attributed to a ZSI scientist
Botton et al. (2022)	Review chapter	Global	Asian range; threats ranked for India
Pramanik et al. (2021)	Review article (56 sources)	National	Stated distribution; trade demand in Maharashtra and Andhra Pradesh
Mohanty (2023)	News report	Odisha, West Bengal, Andaman and Nicobar	Mention of possible remaining populations
Raghunathan and Mondal (2024)	Official checklist (ZSI)	National	Species by state; Schedule, IUCN and CITES status
Wild Life (Protection) Amendment Act, 2022	Legislation (official record)	National	Act number; date of entry into force
IUCN SSC Horseshoe Crab Specialist Group (2025)	Specialist Group report	Global	Current Red List category; reassessment progress

Central Odisha

Central Odisha holds the southernmost documented breeding sites of both species. At Hukitola near Paradip, *T. gigas* and *C. rotundicauda* were recorded on sandy beaches and mangrove mudflats, with eggs and juveniles of both species (Mishra, 2009). On the estuarine

beaches of the Devi estuary in Puri district, nests and juveniles of *T. gigas* were recorded

(Mishra, 2009). These records were gathered during fieldwork between 1988 and 2007. Tripathy et al. (2013) reported densities of 60–100 individuals km^{-1} season^{-1} for the northern and central Odisha coast, with higher values on beaches near river mouths, but did not report central Odisha separately. No source from 2021 onwards reported field data for central Odisha.

Southern Odisha

Two sources contained data for southern Odisha. Mishra (2009) listed *T. gigas* from Chilika and Gopalpur at depths of 20–30 m, with no eggs or juveniles recorded at either locality. Tripathy et al. (2013), who surveyed breeding habitats along the Odisha coast from December 2005 to June 2007, reported a density of 15–20 individuals km^{-1} season^{-1} on the southern Odisha coast. This was the only quantitative estimate located for the region and was between one-fifth and one-third of the 60–100 individuals km^{-1} season^{-1} reported for the northern and central coast.

No record of *C. rotundicauda* was located for southern Odisha. No record of either species was located for the Rushikulya estuary or for the Ganjam coast south of Gopalpur. No morphometric, genetic, community-perception or trade data were located for the region. No field data collected after 2007 were found.

Andhra Pradesh

The ZSI checklist records one species from Andhra Pradesh and describes *T. gigas* as common in northern Andhra Pradesh (Raghunathan & Mondal, 2024). Mishra (2009) reported that *T. gigas* is distributed along the Odisha coast up to the coast of Visakhapatnam, at depths of 20–30 m, and recorded no eggs or juveniles at Visakhapatnam. Tripathy et al. (2013) reported densities as low as about 10 individuals km^{-1} on the adjoining coasts of Andhra Pradesh and West Bengal. *C. rotundicauda* has not been recorded from the state (Raghunathan & Mondal, 2024).

In a 2019 news report, a ZSI scientist was quoted as describing the range of the two species in India as "restricted between Ganga and Godavari estuary along Odisha, West Bengal and Andhra Pradesh coasts" (Ghosh, 2019). The southern limit of *T. gigas* is therefore placed at Visakhapatnam in the peer-reviewed record and at the Godavari estuary in an attributed statement. No record was located for the Godavari mangroves, the Krishna delta or any part of the coast further south. Breeding has not been confirmed anywhere in the state.

Andhra Pradesh is also linked to the species through trade. Pramanik et al. (2021), citing a household survey in Balasore, reported that demand for live horseshoe crabs in Maharashtra and Andhra Pradesh provides income to fishers in north-eastern India, at about INR 50 per crab, with the crabs obtained as incidental catch and purchased by middlemen. The purpose of this demand was not stated.

Tamil Nadu and Puducherry

The ZSI checklist states that there are no reports of either species from Tamil Nadu (Raghunathan & Mondal, 2024). No record was located for Tamil Nadu or Puducherry in any other source, including searches for Pulicat, Pichavaram, Palk Bay and the Gulf of Mannar. The distribution model of Vestbo et al. (2018) indicated suitable habitat for *C. rotundicauda* across the Bay of Bengal, including Sri Lanka. This is a modelled suitability; it was not supported by any field record in the sources reviewed.

West coast

The ZSI checklist states that there are no reports of either species from the west coast of India (Raghunathan & Mondal, 2024). No occurrence record was located for Kerala, Karnataka, Goa, Maharashtra or Gujarat. Vestbo et al. (2018) made no prediction of suitability for the Arabian Sea coast. The only link between the west coast and Indian horseshoe crabs located in this review is the trade demand in Maharashtra reported by Pramanik et al. (2021) (Section 3.5).

Island territories

No peer-reviewed or official record was located for the Andaman and Nicobar Islands, and the islands are not listed in the ZSI checklist (Raghunathan & Mondal, 2024). A 2023 news report stated that "only a few remaining populations might be left in West Bengal and some parts of Andaman and Nicobar" (Mohanty, 2023), but gave no locality, date or source for the islands. No record was located for Lakshadweep.

Legal and Red List status

The current legal and Red List status of both species is summarised in Table 3. Both species are listed in Schedule II of the Wild Life (Protection) Act, 1972, as amended by the Wild Life (Protection) Amendment Act, 2022 (Raghunathan & Mondal, 2024). The amending Act (No. 18 of 2022) entered into force on 1 April 2023 (Wild Life [Protection] Amendment Act, 2022). Before the amendment, horseshoe crabs were listed in Schedule IV, from 2009 (Mohanty, 2023; Pramanik et al., 2021). Sources published after the amendment have continued to cite Schedule IV (Mohanty, 2023), which shows that the change has not yet been fully absorbed into the literature. Pramanik et al. (2021) also noted that the legal definitions in force at the time referred only to *T. gigas*.

Both species are assessed as Data Deficient on the IUCN Red List (Raghunathan & Mondal, 2024). The assessments were published in 1996 under the version 2.3 categories (World Conservation Monitoring Centre, 1996a, 1996b). Reassessment of both species is under way. A draft assessment of *C. rotundicauda* was completed and reviewed by the Specialist Group Co-Chairs, with submission to IUCN planned for the latter half of 2025. A draft for *T. gigas* was expected in 2025, with submission targeted for 2026 (IUCN SSC Horseshoe Crab Specialist Group, 2025). Neither species is listed in the CITES appendices (Raghunathan & Mondal, 2024).

Table 3. Legal and conservation status of the two Indian horseshoe crab species.

Instrument	Tachypleus gigas	Carcinoscorpius rotundicauda
Wild Life (Protection) Act, 1972, as amended in 2022 (in force 1 April 2023)	Schedule II	Schedule II
Previous listing (from 2009)	Schedule IV	Schedule IV
IUCN Red List	Data Deficient (1996; categories version 2.3); reassessment targeted for submission in 2026	Data Deficient (1996; categories version 2.3); reassessment planned for submission in the latter half of 2025
CITES	Not listed	Not listed
Recorded Indian states (ZSI checklist)	Odisha; West Bengal; Andhra Pradesh (northern)	Odisha; West Bengal

Sources: Raghunathan and Mondal (2024); Wild Life (Protection) Amendment Act, 2022; World Conservation Monitoring

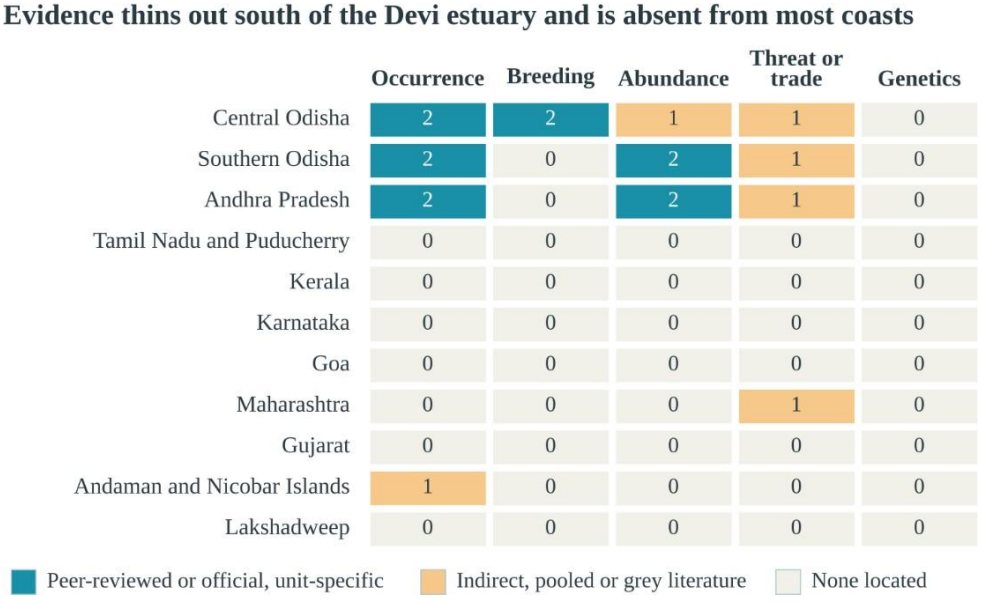


Figure 2. Evidence maps of horseshoe crab data by coastal unit and evidence type. Level 2: peer-reviewed or official evidence specific to the unit; level 1: indirect, pooled or grey-literature evidence; level 0: no evidence located. West Bengal and northern Odisha are outside the scope of the review

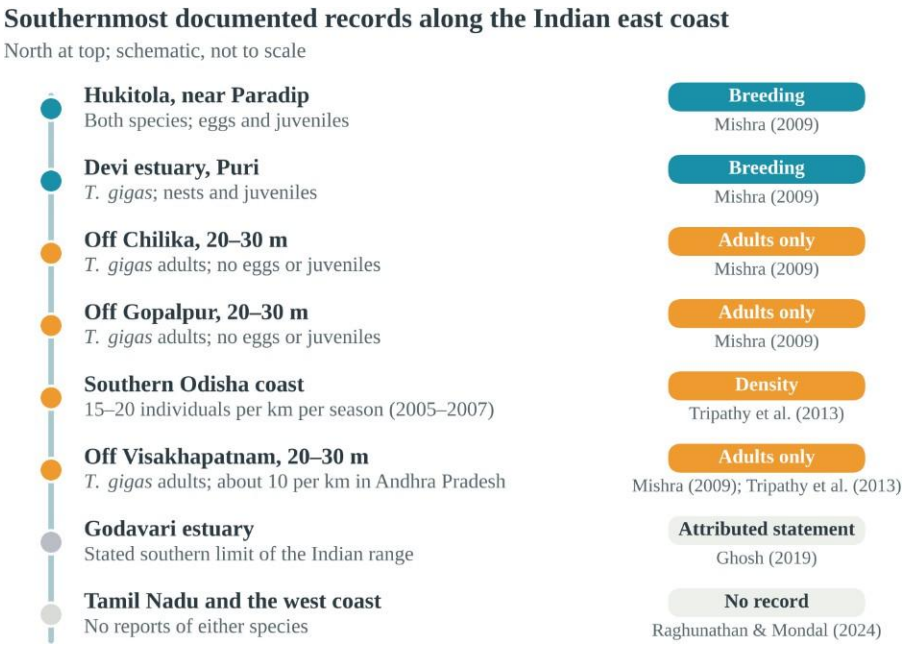


Figure 3. Southernmost documented records of Indian horseshoe crabs, arranged from north to south along the east coast. Sources: Mishra (2009), Tripathy et al. (2013), Ghosh (2019) and Raghunathan and Mondal (2024). The figure is schematic and not drawn to scale

Genetic structure

Sequencing of the cytochrome c oxidase subunit I (COI) gene identified two significantly differentiated groups of *T. gigas* on the Indian east coast (F_{ST} = 0.544, $p < 0.001$), with an estimated 0.11 migrants per generation (Periasamy et al., 2017). The Indian population formed a clade separate from Southeast Asian populations, and the authors described it as isolated and declining. The sampling localities of the two groups were not named in the accessible text. It therefore cannot be determined whether either group corresponds to central–southern Odisha or Andhra Pradesh. Two more recent molecular studies of Bay of Bengal horseshoe crabs, published in 2022 and 2026, were identified but could not be retrieved (Section 4.4).

Evidence map and documented records

The graded evidence is summarised in Figure 2, and the southernmost documented records are arranged from north to south in Figure 3. Central Odisha holds peer-reviewed evidence of occurrence and breeding. Southern Odisha and Andhra Pradesh hold peer-reviewed evidence of occurrence and of abundance, both dated, but no evidence of breeding or genetic data. All other units hold no evidence of occurrence, except a single unsupported news mention for the Andaman and Nicobar Islands and an indirect trade link for Maharashtra.

Discussion

A range margin or a survey artefact?

The evidence reviewed is consistent with a range margin on the central Odisha to northern Andhra Pradesh coast. Breeding of *T. gigas* is documented as far south as the Devi estuary, and breeding of *C. rotundicauda* as far south as Hukitola (Mishra, 2009). South of these sites, only adult *T. gigas* have been recorded, at depths of 20–30 m off Chilika, Gopalpur and Visakhapatnam (Mishra, 2009). Densities fall from 60–100 individuals km^{-1} $season^{-1}$ on the northern and central Odisha coast to 15–20 on the southern Odisha coast and about 10 in Andhra Pradesh (Tripathy et al., 2013). This pattern resembles a breeding core in the north-eastern Bay of Bengal with sparse, possibly non-breeding adults further south.

Three features of the evidence prevent a firmer conclusion. First, the density gradient rests on a single survey conducted between 2005 and 2007, and sampling effort per sub-region was not available in the accessible text. Second, the absence of records from Tamil Nadu,

Puducherry, the west coast and the islands is an absence of evidence, not evidence of absence. No targeted survey of these coasts was located, and the modelled suitability of the Bay of Bengal for *C. rotundicauda* (Vestbo et al., 2018) has not been tested in the field. Third, early literature on Indian horseshoe crabs, including works by Annandale (1909), Sewell (1912), Roonwal (1944) and Ramarao and Suryarao (1972), as cited in Chatterji et al. (1992), could not be retrieved. These works may hold historical records from further south and should be examined before a range limit is asserted.

WHY CENTRAL AND SOUTHERN ODISHA MATTER

Central and southern Odisha are the units in which the question of the range margin can be addressed most efficiently. They contain the southernmost documented breeding sites (Mishra, 2009) and the only quantitative baseline outside the northern core (Tripathy et al., 2013), so a repeat survey would yield a trend estimate over roughly two decades. They lie between the breeding core and the documented southern limit. They may also contain one of the two genetic groups reported by Periasamy et al. (2017); if so, they would represent a distinct management unit. Finally, a margin population would be the first to express the loss of suitability projected for the Bay of Bengal (Vestbo et al., 2018). Whether the threats documented on the northern coast apply further south is unknown. Fishery-related mortality was identified as the main threat in the 2005–2007 survey, with nearly 1,000 dead crabs stranded per season (Tripathy et al., 2013), but these data were not reported by sub-region in the accessible text. The trade demand reported in Maharashtra and Andhra Pradesh (Pramanik et al., 2021) indicates that the species is linked to other states through trade even where it does not occur. Neither the scale of this trade nor its effect on southern populations has been measured.

IMPLICATIONS FOR STATUS ASSESSMENT

Both Indian species remain Data Deficient on the basis of assessments published in 1996 (World Conservation Monitoring Centre, 1996a, 1996b), and reassessment is under way (IUCN SSC Horseshoe Crab Specialist Group, 2025). The present review shows that the deficiency is spatial as well as temporal. Data are absent for most of the national coastline and are more than 15 years old for the documented range margin. A national contribution to the reassessment would require, at minimum, confirmation of the southern limit of each species, abundance data for the margin as well as the core, and the location of the genetic groups along the east coast.

The listing in Schedule II applies to the entire coastline (Raghunathan & Mondal, 2024). However, the published conservation and monitoring effort remains concentrated in the north (Pramanik et al., 2021; Shaik et al., 2024; Panda et al., 2025). Conservationists have also urged the central and Odisha state governments to devise a species recovery plan (Mohanty, 2023). Any such plan would require baseline data for central–southern Odisha and Andhra Pradesh, which do not currently exist in published form.

LIMITATIONS

The search was conducted through open indexes and publisher platforms; subscription databases (Scopus, Web of Science) were not queried, and only English-language sources were considered. Screening and extraction were carried out by a single reviewer, although each extracted value was checked a second time against its source. Nine records could not be retrieved in full: the ZSI status survey report of Tripathy, Mohapatra and Mukhopadhyay (2018); a 2022 mitochondrial DNA study and a 2026 DNA-barcoding study of Bay of Bengal horseshoe crabs; a habitat-mapping study; an article on conservation needs in the *Records of the Zoological Survey of India*; an inventory of Odisha crustaceans; a Japanese repository document; the IUCN Red List species pages; and the Schedules of the 2022 amending Act. The schedule listing was therefore taken from the ZSI checklist (Raghunathan & Mondal, 2024) and not from the Gazette text. Two of the 11 included sources are news reports and were used only for attributed statements. Replication of the search in subscription databases, with dual independent screening and direct consultation of the Gazette and the IUCN Red List, is recommended.

RESEARCH PRIORITIES

The evidence gaps, the evidence on which each rests and the action required to address it are summarised in Table 4.

Table 4. Evidence gaps and research priorities for horseshoe crabs outside West Bengal and northern Odisha.

Gap	Current evidence	Priority action	Unit
No abundance data after 2007	Single survey, 2005–2007 (Tripathy et al., 2013)	Repeat standardised spawning-beach counts at full- and new-moon spring tides	Central and southern Odisha; northern Andhra Pradesh
Breeding unconfirmed south of the Devi estuary	Adults only, at 20–30 m, off Chilika, Gopalpur and Visakhapatnam (Mishra, 2009)	Systematic searches for nests, eggs and juveniles on estuarine beaches	Southern Odisha; Andhra Pradesh
Southern range limit unresolved	No record south of Visakhapatnam (peer-reviewed) or the Godavari estuary (attributed statement)	Structured fisher interviews, landing-centre bycatch checks and environmental DNA sampling	Andhra Pradesh; Tamil Nadu; Puducherry
West coast and islands unsurveyed	No record (Raghunathan & Mondal, 2024); one unsupported news mention for the Andaman and Nicobar Islands	Rapid presence–absence surveys of estuaries and mangrove creeks	West coast; island territories
Genetic structure at the margin unknown	Two groups on the east coast, localities not named (Periasamy et al., 2017)	COI and nuclear-marker sampling from central–southern Odisha and Andhra Pradesh	Central and southern Odisha; Andhra Pradesh
Trade flows unquantified	Demand reported in Maharashtra and Andhra Pradesh (Pramanik et al., 2021)	Market surveys and enforcement records under Schedule II	Andhra Pradesh; Maharashtra
Historical records unexamined	Early works cited but not retrieved (Chatterji et al., 1992)	Archival search of early literature and ZSI museum collections	All units

CONCLUSIONS

Outside West Bengal and northern Odisha, the published evidence on India's horseshoe crabs is sparse, dated and largely limited to presence records. Breeding of *T. gigas* is documented as far south as the Devi estuary and that of *C. rotundicauda* as far south as Hukitola. Further south, adult *T. gigas* have been recorded at depth off Chilika, Gopalpur and Visakhapatnam, and the only density estimates for southern Odisha and Andhra Pradesh date from 2005–2007. No record of either species has been published for Tamil Nadu, Puducherry, the west coast or Lakshadweep, and the only mention of the Andaman and Nicobar Islands is unsupported. Both species are listed in Schedule II of the Wild Life (Protection) Act, 1972, as amended in 2022, and both remain Data Deficient on the IUCN Red List pending reassessment.

The central inference is that the documented southern margin of India's horseshoe crabs coincides with the southern limit of research effort, and the two cannot yet be separated. Central and southern Odisha are the units in which this question can be resolved most efficiently, because they hold the southernmost breeding records and the only quantitative baseline outside the northern core. Until data from the margin are collected, national contributions to the Red List reassessment will rest on evidence from a small fraction of the Indian coastline.



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Rethinking India's blue carbon future: from coastal habitats to marine sediments

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CONTEXT

The current climate change crisis requires strong, effective measures from all the world's nations combined. The 2025 World Meteorological Organization report highlighted that India is increasingly experiencing extreme heatwaves, erratic monsoons, floods and droughts, with severe damage to the economy and human well-being. For example, 450 premature deaths were attributed to intense heatwaves in 2024. Through the National Action Plan on Climate Change (NAPCC), India has made substantial investments in renewable energy and reported a 36% reduction in emissions per unit of GDP between 2005 and 2020 (Government of India, 2026). India has made strong progress in renewable energy; however, stronger policy implementations in other carbon sequestration areas is still needed to meet the net-zero target.

India's climate policy recognises natural carbon sinks, including forest and tree cover, as a form of green carbon sequestration. India's updated report on its Nationally Determined Contribution (NDC) aims to create an additional carbon sink of 3.5-4.0 billion tonnes of CO_2 equivalent by 2035 (Government of India, 2026). When annualised, this is equivalent to roughly 4% of India's current annual CO_2 emissions. According to the 2019 Intergovernmental Panel on Climate Change (IPCC) report, "*Natural processes per se, although important to the climate system and the global carbon cycle, are not a mitigation response. Two management approaches are possible: first, actions to maintain the integrity of natural carbon stores, thereby decreasing their potential release of greenhouse gases, whether caused by human or climate-drivers; and second, through actions that enhance the long-term (century-scale) removal of greenhouse gases from the atmosphere by marine systems, primarily by biological means.*" Current IPCC guidance allows countries to include managed coastal wetlands, such as mangroves, salt marshes, and seagrasses, in NDC-related reporting. First popularised through the United Nations Environment Programme (UNEP) report 'Blue Carbon: The Role of Healthy Oceans in Binding Carbon', the term 'blue carbon' initially referred to organic carbon stored in vegetated coastal ecosystems such as mangroves, salt marshes and seagrass meadows (Nellemann et al., 2009). Since then, climate scientists and, more recently, climate policymakers have expanded the concept to include a wider range of coastal and marine carbon stores, including tidal flats and continental shelf sediments (James et al., 2024).

India's annual carbon sequestration potential through recognised blue carbon ecosystems is significant, estimated at nearly 1-3 teragrams (10^{12} grams) of carbon (Tg C) (Bertram et al., 2021). The same study further suggests that India could benefit significantly from global protection of blue carbon ecosystems, as carbon stored by these ecosystems anywhere in the world ultimately helps reduce climate risks for vulnerable countries such as India. This is why it is important to increase the overall awareness of blue carbon protection within India. Effective management and restoration of these ecosystems can strengthen national carbon sinks, protect vulnerable coastlines and make India's climate policy more ecosystem-friendly. In this context, with a coastline of more than 7500 km and mangroves contributing about 3% of global mangrove cover, India has the potential to strengthen its focus on blue carbon ecosystems, both as a research priority and as part of its policy framework. Importantly, India's NDC also recognises coastal regions as vulnerable sectors requiring effective adaptation management plans for agriculture, water resources, health, and the combating of natural disasters. Effective coastal zone management also improves the livelihoods of coastal people who depend on natural resources.

Undoubtedly, population growth remains one of the major anthropogenic drivers of ecosystem disturbance in India, particularly through the encroachment of otherwise relatively undisturbed habitats for human settlement (Antony et al., 2025). Other pressures, including fish and shrimp farming, also remain major threats in mangrove zones. InVEST, a biophysical modelling framework, suggests that carbon stocks in the Sundarbans mangrove system in West Bengal alone declined by approximately 6 Tg C between 1975 and 2020, attributed to anthropogenic disturbances in addition to natural drivers, such as salinity and sea-level change (Bera et al., 2022).

Blue carbon awareness in India

India has already begun to recognise the importance of mangroves as nature-based climate solutions for carbon sequestration and has implemented several national and state-level policies for mangrove management, such as the Coastal Regulation Zone notification (CRZ, 1991) and the Mangrove Initiative for Shoreline Habitats and Tangible Income (MISHTI, 2025). In this context, it is important to note that the Indian Sundarbans Mangrove Restoration project, which aimed to plant 56 km^2 of mangroves within three years and was estimated to store 0.7 Tg C in biomass and soil over twenty years, has been recognised as a successful carbon management project (Wylie et al., 2016). The growth of research on blue carbon assessment is also evident in increasing biomass and soil (sediment) carbon assessments, as well as in review studies from 2015 onwards (Antony et al., 2025). However, studies have consistently focused on the mangrove ecosystem, which stores 67 Tg C, with less attention to seagrass (0.063 Tg C) and salt marsh ecosystems (0.0049 Tg C) (Akhand et al., 2023). These estimates include above-ground and below-ground biomass, as well as organic carbon stored in sediment.

While biomass carbon is important, sediment organic carbon provides longer-term sequestration. Tropical mangroves provide ideal anoxic (oxygen-poor) conditions for effective storage and burial, allowing them to remain buried for millennia if undisturbed (James et al., 2024). Previous studies also show that in some mangrove areas in Kerala, the median organic carbon accumulation rate in sediments can reach 193 g C $m^{-2}yr^{-1}$, slightly higher than the global average of 163 g C $m^{-2}yr^{-1}$ (Rani et al., 2021). Although scattered data from the Sundarban mangrove show that the organic carbon accumulation rate may be lower and variable, the InVEST model predictions indicate that under an ideal conservation and management scenario, parts of the Sundarban mangroves could increase carbon accumulation to exceed 17 kg C m^{-2} by 2050 (Mondal et al., 2026). However, such modelled estimates depend on conservation scenarios, sediment dynamics, and depth-integrated organic carbon profiles, highlighting the importance of analysing deeper sediments rather than relying solely on surface carbon stock measurements to understand long-term carbon sequestration.

Overall, India has significant potential to successfully leverage its blue carbon ecosystem and nature-based carbon sequestration. Effective management may help meet several Sustainable Development Goals (SDG 13: Climate action, SDG 14: Life below water, and SDG 15: Life on Land) by linking carbon sequestration to coastal conservation and biodiversity protection, ultimately improving India's NDCs. Despite this, blue carbon is still not treated as a measurable carbon-accounting category within India's climate policy, and existing initiatives remain more strongly framed around conservation, coastal protection, and livelihoods than long-term sediment carbon storage.

Future direction: priority questions

Recent priority-setting work on India's blue carbon ecosystems, along with a few recent reviews (Akhand et al., 2023; Antony et al., 2025; Austin et al., 2026), recognises the need to integrate blue carbon more explicitly into national policy, following a detailed evaluation of its potential, including the often-overlooked seagrass and salt marsh ecosystems. The inconsistency in carbon stock estimates across different sediment depths

within blue carbon ecosystems is also noted (Austin et al., 2026). As mentioned before, although biomass stocks and soil organic carbon have been measured in some areas, studies on carbon accumulation rates remain limited. These rates are important because they indicate not only how much carbon is stored, but how quickly carbon is being buried and retained over climate-relevant timescales. Beyond mapping carbon stock and accumulation rates, the other priority questions framed in the above-mentioned work include blue carbon's role in climate mitigation in the Indian context, long-term ecological monitoring, restoration and co-benefits, biodiversity targets, livelihood diversification, and, ultimately, building awareness for operational policy and community engagement.

However, the next priority should go beyond estimating carbon stocks and accumulation rates alone. From a blue carbon conservation perspective, India needs to ask how secure this stored carbon stock is against future environmental and human disturbance. The permanence and long-term fate of stored carbon stock depend not only on the immediate above- and belowground biomass but also on the distribution of carbon stock with depth, carbon degradability or reactivity, and the depositional environment. These factors, in turn, are influenced by organic matter sources, sediment transport pathways, grain size, burial conditions and post-depositional disturbance. For example, carbon stored in deeper, finer-grained sediments deposited under past in situ anoxic conditions likely has longer-term preservation potential and may require careful management to mitigate anthropogenic disturbance at depth.

CONNECTING DISCIPLINES FOR INDIA'S BLUE CARBON FUTURE

India's blue carbon future could benefit from a wider source-to-sink approach, and available Quaternary (past 2.6 million years) sedimentological studies could add a new dimension to India's blue carbon research. Mangroves, estuaries, tidal flats, deltas and continental shelf sediments are connected through sediment transport, organic matter burial and disturbance pathways. This perspective is particularly relevant for India because several studies have already examined changes in sediment dynamics and organic matter degradation in the Sundarbans and the broader Ganges-Brahmaputra floodplain-delta (e.g., Prasad et al., 2017; Sreemany & Bera, 2022), often in the context of palaeoclimate reconstruction, rather than blue carbon policy. Also, palynological (pollen) studies of Quaternary sediments from Kerala-Maharashtra coast indicate a decline of mangroves in response to a changing environment from 3500 to 1500 years before present, whereas the emergence of mangroves is especially facilitated in the least disturbed areas under changing monsoon conditions (Limaye et al., 2014).

This approach could directly complement some priority questions identified by Austin et al. (2026), particularly the need for improved mapping, standardised carbon measurements, better estimates of accumulation rates and clearer pathways for incorporating blue carbon into policy. A sediment-focused approach would extend these priorities by asking not only where blue carbon ecosystems are located and how much carbon they store, but also how securely that carbon is buried and how vulnerable it is to future disturbance. Interestingly, a few scattered data points on carbon degradability from Indian mangrove sediments are also available, in which researchers measured that ~50% of the refractory (less degradable organic matter, such as humic and fulvic acid) fraction was present, with this fraction decreasing with depth, thereby allowing them to estimate degradation rates (Barik et al., 2021).

Therefore, the gap is not a lack of data on organic carbon in sediments. Rather, the opportunity lies in analysing and integrating existing sedimentological, geochemical, and palaeoenvironmental datasets with emerging blue carbon questions. Such integration could help bridge India's strong coastal sediment research tradition with current needs for carbon accounting, conservation planning and climate mitigation.

EXPANDING THE BLUE CARBON ECOSYSTEM: THINKING BEYOND TRADITIONAL HABITATS

Although mangroves should remain the first priority for improving the confidence of evidence and policy translation, followed by seagrasses and salt marshes, India can eventually expand traditional blue carbon habitats into coastal shelf areas as well. Certainly, the continental shelf of India is much narrower and has a smaller area (~0.5 million km2) than most of the studied shelf areas for blue carbon research, such as the Northwest European Shelf (~1.1 million km^2).

A logical next step is to begin considering continental-shelf sediments within a broader blue-carbon research framework. This is feasible because, as discussed above, India already has several studies along both the eastern and western coastlines that focus on palaeoclimate reconstruction, sediment sourcing, and Quaternary environmental change. In many of these studies, sediment cores are collected and analysed at high resolution, often accompanied by extensive geophysical data (e.g. Krishna et al., 2013). With appropriate additional measurements, these datasets could be used to derive carbon stock and burial assessments.

The current global trend in shelf blue carbon research is increasingly focused on estimating carbon loss from the shelf due to anthropogenic disturbances such as bottom trawling. This is relevant to India because coastal communities are highly dependent on fishing, and some previous studies have reported changes in sediment structure and organic matter under intensive trawling pressure (e.g., Bhagirathan et al., 2010). In this way, India has an opportunity not only to strengthen work on recognised blue carbon ecosystems, but also to broaden and maximise the overall benefits of coastal and marine carbon research. This would, in the future, benefit India's marine spatial planning policy for marine protected areas, not only by protecting biodiversity but also by accounting for long-term carbon storage on the shelf.

Both state and national institutions will need to collaborate to standardise mapping and measurement within a consolidated framework. Environmental NGOs, community-based organisations and voluntary carbon market actors can also help by supporting blue carbon-focused research, monitoring and management. The goal is not necessarily to create completely new projects, but to make existing conservation, restoration and coastal management projects more carbon-aware and policy-relevant. In this context, it is worth noting that an upcoming international conference, the INQUA (International Quaternary Association) Congress 2027, is being held in Lucknow, India, with the tagline '*Quaternary Science As Societal Services*', which emphasises how the scientific community can contribute to a country's socio-economic development. Hence, India's intent to employ science for societal benefits, interest in nature-based blue carbon solutions, and its future potential can help move the country towards a more sustainable, carbon-smart future.

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Vox Populi



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A Life Between Floods and Survival

Scripted by Sujay Bhattacharjee, Progyan Foundation for Research and Innovation (PFRI), research wing of the South Asian Forum for Environment (SAFE)

"My life has been a continuous struggle to protect my family from floods, hunger, and poverty. Every year, I work hard to earn a living, but when the floods arrive, everything I have worked for is put at risk."

I am Hareram Shaw, a resident of Gorgama village in Matihani block of Begusarai district, Bihar. I belong to a family of five dependents, including my wife, three children, and my elderly mother. For nearly a decade, periodic floods of the Ganga have repeatedly threatened my home, livelihood, and hopes for a better future. In 2015, my house near the natural barrage area of the Ganga was washed away by the floodwaters. I had to leave the place where I had lived and move to Gorgama village, hoping to rebuild my life. But displacement did not bring security. During the monsoon of July-August 2026, my house was swept away again, leaving my family struggling to find safety and stability. For me, every flood means losing not only a shelter but also the little security I have managed to build through years of hard work.

I work as a leased farmer, cultivating land that does not belong to me. The difficult soil and flood-prone conditions leave me with limited agricultural opportunities, and I mainly cultivate crops during the Rabi season. After harvesting, I sell my produce in the nearest market, but the income is not enough to meet my family's basic needs. Alongside farming, I make baskets from 'बेंत' (cane-like weaving material) to earn a little extra money. Yet, these efforts cannot protect us from repeated disasters and economic hardship. When local livelihood opportunities fail, I migrate to Kolkata and Uttar Pradesh to work at construction sites. Leaving my family behind is painful, but I have little choice when there is no reliable source of income at home. I have also tried several times to seek government assistance for livelihood support, but I have not succeeded in obtaining the help my family needs.

My greatest worry is my children's future. There are days when arranging enough nutritious food for everyone becomes difficult. My children's health and nutrition suffer when our income falls short, while my elderly mother also needs care. Living in an uncertain home, struggling for food, and facing recurring floods have made everyday life a constant battle for survival. My story is not mine alone. Many families in the flood-affected villages of Matihani face similar hardships. We are farmers without secure land, workers who must migrate for survival, and families who repeatedly lose their homes and belongings to the floods. We do not ask for sympathy alone. We need secure housing, accessible livelihood assistance, agricultural support, food and nutrition security, and rehabilitation that reaches the people who need it most.

I want my children to grow up in a home where they do not have to fear the next flood or go hungry because their father cannot find work. I want to earn a living in my own village rather than migrate every year in search of survival. Until families like mine receive meaningful support, the cycle of displacement, poverty, and hunger will continue.



News Hamlet



Where have the Ancient Guardians Gone?

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Have you ever walked through a forest and wondered how old the trees are? During my recent visit to the forests of Manipur, I found myself asking this same question repeatedly. From above, the hills appeared green and full of life, yet something felt missing, unlike what I had learned in geography books, where Manipur is described as having tropical moist deciduous and semi-evergreen forests with trees of significant girth, often exceeding 100 cm in diameter at breast height (DBH) (Champion & Seth, 1968; FSI, 2021). I could hardly find truly old, large trees, the kind that have existed for centuries. Most of the trees I observed seemed relatively young, often not more than a few decades old. This made me question what had happened to the century-old trees that once defined these landscapes.

The state of Manipur, in the northeastern part of India, has long been known for its rich forests and diverse ecology. In earlier times, its hills were covered with dense tropical forests, with tall canopies forming layered and self-sustaining ecosystems. These forests were not only important for biodiversity but also played a crucial role in supporting terrestrial water systems, agriculture, and regional livelihoods. Natural springs, often considered among the purest sources of drinking water and commonly found in hills, are strongly dependent on healthy forest ecosystems. In particular, deep-rooted trees enable rainwater to slowly infiltrate the soil and recharge underground aquifers (Bruijnzeel, 2004; Negi & Joshi, 2002).

The disappearance of these old trees did not happen suddenly but is the result of long-term exploitation of forest resources. One major factor was large-scale logging during the pre-independence period, when timber was extracted extensively to meet external demands (Gadgil & Guha, 1992). During the post-independence, forests continued to face pressure due to the growing demand for wood for rural housing, fuel, and small-scale industries. Over time, this led to a further reduction of mature trees. Another important factor is the widespread practice of Jhum cultivation, also known as shifting cultivation (Plate 1). This traditional farming method involves clearing and burning forest patches for subsistence cropping. While it was once practiced sustainably with long fallow periods (10–12 years) that allowed forests to regenerate, increasing population pressure has shortened these cycles to 2–3 years in many areas (Ramakrishnan, 1992; Lele & Joshi, 2009).



Plate 1. *Tree stumps on Jhum field slopes indicating widespread logging of large, mature trees*

As a result, forests do not get enough time to recover fully and return to advanced stages of ecological succession.

Today, much of the green cover visible across Manipur is not primary forest but what ecologists call secondary or regenerating forest (Chazdon, 2014), which has grown back after disturbances such as logging, burning, or land reclaiming. Although this regrowth reflects the resilience of nature, it is not the same as primary forest structure. Young tree stands often lack structural complexity (i.e. multi-layered canopy, presence of large-diameter trees, and diverse age classes) and ecological functions (i.e. high biomass storage, stable nutrient cycling, and efficient water infiltration) of older forests (FAO, 2010; Chazdon, 2014). In many places, the landscape shows signs of repeated disturbance, with exposed slopes, patches of low vegetation, and remnants of burnt trees (Plate 2) that resemble a silent graveyard of what were once large forest stands.



Plate 2. *Burnt and surviving century-old Phoebe hainesiana trees along both sides of the pathway*

Over time, forest disturbance has reduced groundwater recharge, causing many springs to weaken or dry up. In the hilly parts of Manipur, where settlements have long depended on springs for drinking water, this decline is directly affecting daily life and increasing reliance on distant water sources. The pattern is uneven, as northern districts with relatively better forest cover still sustain more springs, while several southern districts, marked by deforestation and exposed slopes, face growing water scarcity. These trends reflect a clear link between land use, forest condition, and water availability, highlighting the changing dynamics of the regional political ecology.

Disappearance of the century-old trees in Manipur is not only a loss of forests but also a broader environmental shift in the landscape that connects land, water, and indigenous cultural heritage. Moving forward, restoring forest health through protection, longer regeneration cycles, and community-led management can gradually rebuild these ecological systems. At the end, the fading presence of old trees reminds us that ecosystems are fragile, and that their restoration is essential for sustaining water, livelihoods, and the future of these landscapes.

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When a Mountain Collapse Becomes a River Disaster

Understanding the 2026 Rasuwa flash flood and the chain of hazards that followed

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On 26 August 2026, a sudden flood swept through Nepal's Rasuwa District, close to the border with China. Water, mud, rock and boulders moved through the Lhende Khola, Bhote Koshi and Trishuli river corridors, damaging settlements, transport links and border infrastructure. The surge also put hydropower facilities and communities farther downstream at risk. Initial reports described a major flash flood; subsequent scientific assessments linked it to a high-altitude rock-and-ice collapse near Langtang Lirung (International Centre for Integrated Mountain Development [ICIMOD], 2026b; U.S. Geological Survey [USGS], 2026).

The distinction matters. This was not a typical flood that can be explained by rainfall alone, nor has it been described in the latest scientific synthesis as a conventional glacial lake outburst flood (GLOF). Instead, researchers describe a cascading mountain hazard: a failure high on a steep slope set off a sequence of events that carried debris and a powerful surge into river valleys. The precise mechanics of the collapse are still being examined (ICIMOD, 2026d).

From mountain slope to downstream surge

According to ICIMOD's assessment, a large mass of rock and glacier ice detached from the northern face of Langtang Lirung, a 7,227-metre peak, shortly after 8:37 a.m. local time. The material fell roughly 1,200 metres into the Lhende Khola valley, fragmented, and mixed with meltwater, river water and loose sediment. As it moved downhill, it gathered additional debris and became a fast-moving flow that entered the Bhote Koshi and continued into the Trishuli system (ICIMOD, 2026d).

The USGS estimated that the debris flow and flood travelled nearly 100 kilometres, carrying the consequences far beyond the place where the slope failed. ICIMOD's initial event update reported that water levels at Galchchi on the Trishuli rose by as much as nine metres within 30 minutes. The figures show how quickly a mountain event can become a downstream emergency, leaving little time for people and infrastructure in its path to respond (ICIMOD, 2026b; USGS, 2026).

The flood also illustrates why different hazards should not always be assessed separately. A rockfall or ice-rock avalanche can enter a river, move large quantities of sediment and boulders, temporarily obstruct a channel, or produce a sudden surge downstream. Each stage can change the nature and scale of the next. In such circumstances, a flood is not necessarily the first event in the chain; it may be one of its later consequences.

What the evidence tells us and what it does not

The scientific understanding of the Rasuwa disaster has developed since the first reports. The USGS initially described a rapid slope failure involving a glacier as the likely trigger, while noting that it was not yet clear whether the event was a landslide that incorporated glacier ice or a collapse of glacial material. ICIMOD's October 2026 synthesis describes it as a cascading cryospheric geohazard and explains that the exact failure process remains under investigation (ICIMOD, 2026d; USGS, 2026).

The October synthesis also reports evidence of movement before the collapse. Satellite radar observations detected up to 40 centimetres of slope movement in the satellite's viewing direction between 7 July and 24 August 2026. Researchers estimate that about 132 million cubic metres of rock and glacier ice detached from the mountain. These are important

findings, but they do not mean the exact time of failure could have been predicted. Detecting movement, interpreting what it means and issuing a useful warning are separate tasks (ICIMOD, 2026c, 2026d).

THE CLIMATE QUESTION NEEDS CARE

The event has also raised questions about climate change and Himalayan glaciers. The wider context is important: across the Hindu Kush Himalaya, warming is changing glaciers, snow conditions, permafrost and mountain environments. These changes can influence the conditions in which high-altitude hazards develop. However, the existence of a warming trend does not, by itself, prove that climate change caused a particular slope to collapse.

ICIMOD's initial assessment said it was too early to determine what role climate change played in the Rasuwa event. The later synthesis offers a more detailed account of the physical processes and evidence of slope movement, but continues to treat the collapse mechanism as a scientific question under investigation (ICIMOD, 2026b, 2026d). It is therefore more accurate to distinguish between the changing climate context and the specific trigger of this individual disaster, rather than presenting one as a settled explanation for the other.

CONNECTING MONITORING WITH PREPAREDNESS

One lesson from Rasuwa is the value of viewing mountain slopes, rivers and settlements as parts of a connected system. Satellite observations can help identify movement on unstable slopes. Ground instruments and seismic data can add information about changing conditions, while river gauges can track downstream changes. None of these tools can guarantee advance notice of every sudden collapse, particularly in remote terrain, but combining them can improve understanding of where risks may be developing.

Risk assessments can also examine what happens after a slope fails: how much material may enter a river, where debris could accumulate, whether a temporary blockage could form, and which roads, bridges, settlements or energy facilities lie downstream. This type of assessment considers the full chain of possible impacts rather than looking at rainfall, landslides and flooding as unrelated events.

Warning systems are most useful when people can act on the information they receive. Clear evacuation routes, safe places on higher ground, reliable ways to communicate alerts and regular community drills can support faster decisions. In areas used by workers, visitors and people travelling across the border, warnings also need to reach people who may be unfamiliar with the terrain or local alert systems. Because mountain river systems across national boundaries, timely sharing of hazard information between neighbouring regions can be part of that preparedness (ICIMOD, 2026a).

These measures are not a promise that every disaster can be prevented. They are practical ways to reduce the gap between observing a hazard and helping people move to safety. The Rasuwa event shows why that gap matters: a process that begins high on a mountain can affect communities many kilometres away, often within a very short period.

LOOKING BEYOND THE FLOOD

The 26 August disaster is a reminder that mountain hazards do not always remain confined to the mountains. A slope failure can become a debris flow, a river surge and an infrastructure emergency in one connected sequence. Understanding those connections can help researchers, communities and infrastructure planners recognise risks that may be missed when each hazard is considered in isolation.

Important questions remain about the exact failure process and the role, if any, of climate change in this particular event. What is already clear is the need to combine careful scientific investigation with monitoring, practical warnings and preparedness along the routes through which a hazard may travel. In the Himalaya, looking upstream can be essential to protecting people downstream.

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Mangrove Restoration under the MISHTI Programme in India: A Review of Ecological Restoration, Governance and Just Transition

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INTRODUCTION

Mangrove ecosystems contribute to shoreline stabilisation by influencing sediment dynamics and reducing wave energy. They sustain estuarine biodiversity, including nursery grounds for fish and invertebrates, and support climate-change mitigation through blue-carbon sequestration in vegetation and coastal sediments (Lo, 2026). The Forest Survey of India (FSI, 2024) estimated national mangrove cover at 4,991.68 km². West Bengal (2,119.16 km²), Gujarat (1,164.06 km²) and the Andaman and Nicobar Islands (608.29 km²) contain the largest concentrations. The remaining cover is distributed across Andhra Pradesh, Maharashtra, Odisha and other coastal jurisdictions.

The national assessment also indicates a net decline of 7.43 km² from the revised 2021 estimate to 2023, despite increases in some states (FSI, 2024). Changes in mapped extent, however, do not fully reflect ecological degradation. Mangroves face continuing pressures from land conversion, coastal construction, altered freshwater and tidal flows, pollution and climate-related changes in habitat suitability (Lo, 2026; Samal et al., 2025). These pressures justify restoring ecological function rather than concentrating on canopy extent alone.

The Government of India introduced the Mangrove Initiative for Shoreline Habitats and Tangible Incomes (MISHTI) in June 2023 with the objective of rehabilitating degraded mangroves and establish vegetation where ecological conditions permit. Coastal protection, biodiversity conservation and carbon sequestration are central to its design. MISHTI also envisages wage employment in restoration activities, alongside assistance for alternative sources of income (Ministry of Environment, Forest and Climate Change [MoEFCC], 2023). However, restoration work may end before long-term maintenance needs cease. Restoration decisions may also restrict fishing and customary resource use, with economic benefits distributed unequally (Jain et al., 2025; Lo, 2026; Subroto et al., 2026). These are documented concerns in the wider literature, not established outcomes of MISHTI. They provide the basis for assessing the programme through a just-transition perspective, concerned with decent work, secure livelihoods, participation and equitable treatment of affected communities (International Labour Organization [ILO], 2015). This review therefore evaluates MISHTI's design, implementation and habitat safeguards, with particular attention to employment standards and equitable livelihood outcomes.

POLICY DESIGN AND INSTITUTIONAL ARRANGEMENTS

MISHTI's original framework proposed interventions across approximately 540 km² between 2023 and 2028. It projected the creation of 22.8 million workdays and an additional carbon stock of around 4.5 million tonnes (MoEFCC, 2023). The guidelines cover enrichment of damaged stands, treatment of gaps in existing vegetation, rehabilitation of abandoned saline aquaculture sites and disused salt pans, and re-establishment of mangroves on tidal land that has a documented history of supporting them.

Implementation rests primarily with state forest departments. District and state coordinating bodies are expected to bring together the authorities responsible for forestry, rural development and other relevant activities. The initial financial arrangement envisaged approximately 70% of resources from the Compensatory Afforestation Fund Management and Planning Authority (CAMPA), with wage-employment budgets and additional public sources expected to provide the balance (MoEFCC, 2023). Such convergence offers access to established funding and administrative systems. It also creates a requirement for clear divisions of responsibility, particularly when planting, worker remuneration and measures to expand household income are financed separately. The guidelines designate restoration works as core activities, but classify enterprise support, training and community tourism as ancillary measures. This difference is substantive- restoration tasks have defined phases and site-based plans, whereas the scale and expected economic results of livelihood interventions are less clearly specified. Enterprise-level objectives may be specified in individual project plans, but these cannot be established from the national guidelines alone.

In July 2026, National CAMPA approved another ₹500 crore for MISHTI, raising the authorised provision to ₹600 crore and extending its duration to 2029. The same announcement recorded ₹88.40 crore in releases to six states or Union territories and proposed a broader approach to managing connected coastal ecosystems (MoEFCC, 2026b). This extension offers an opportunity to align investment decisions more closely with ecological conditions and the needs of participating communities.

IMPLEMENTATION EVIDENCE AND ECOLOGICAL OUTCOMES

The parliamentary response of July 2025 reported that 26,396.34 hectares had entered restoration activities across the financial years 2023–24 and 2024–25. Existing programmes operating in convergence accounted for 22,560.34 hectares, while the remaining 3,836 hectares were supported through National CAMPA gap financing (MoEFCC, 2025a). Reporting by state reveals substantial variation. Gujarat accounted for 19,220 hectares within the convergence figures; Odisha recorded 761 hectares and West Bengal 10 hectares. Under a distinct National CAMPA component, Odisha received support for 89 hectares and West Bengal for 478 hectares, with initial funding of ₹0.70 crore allocated to Odisha and ₹3.74 crore allocated to West Bengal (MoEFCC, 2025a, 2025b). These are distinct funding categories and cannot be combined without specifying their basis. A subsequent Rajya Sabha reply, dated 12 March 2026, reported 9,536 hectares under National CAMPA gap financing, while the convergence figure remained 22,560.34 hectares. For the gap-funded component, it recorded ₹88.40 crore allocated or released and ₹15.46 crore utilised (MoEFCC, 2026a). These updated figures represent reported interventions and expenditure, rather than verified ecological recovery.

The official figures document the geographical extent of interventions, rather than the area that has regained ecological function. Restoration performance also depends on survival, natural regeneration, tidal connectivity and the return of habitat conditions favourable to native species. The March 2026 parliamentary reply confirms that survival assessments inform corrective maintenance following site inspections, but provides no comparable account of ecological recovery across MISHTI locations (MoEFCC, 2026a). An associated concern is the selection of land for planting. Natural tidal flats are not necessarily degraded mangrove forests, and planting upon them may alter functions that measurements of tree cover cannot capture. Under the Coastal Regulation Zone Notification, 2019, mangroves, biologically active tidal flats and habitats used by horseshoe crabs all fall within the CRZ-IA classification (MoEFCC, 2019). Appropriate screening is therefore necessary where intended sites overlap these habitats. In landscapes such as Bhitarkanika, ecological assessment should establish both the suitability for mangrove recovery and the conservation value of adjacent unvegetated areas. Restoration that compromises an existing sensitive habitat would be inconsistent with the programme's wider conservation rationale.

EMPLOYMENT AND JUST-TRANSITION CONSIDERATIONS

The employment component of MISHTI derives chiefly from labour required for nurseries, site preparation, planting and early maintenance. Its work schedule progresses from planning and establishment to stabilisation and eventual exit (MoEFCC, 2023). Consequently, the projected workdays describe the anticipated volume of labour, but provide limited information about employment continuity or the distribution of earnings among coastal households. This distinction becomes relevant because maintaining restored habitats can require attention after the principal funded activities have ended.

The International Labour Organization's (2015) just-transition framework situates environmental change within a wider set of labour and social obligations, including decent employment, protection against economic insecurity and participation in public decisions. MISHTI envisages skills development and resident participation, with remuneration governed by the rules applicable to each financing source. Its guidelines also establish concurrent monitoring at national and local levels, with annual implementation and expenditure reports as well as independent site reviews at five-year intervals (MoEFCC, 2023). However, they do not prescribe nationally comparable indicators for wages received, working conditions, occupational safety, gender disparities or continuity of paid work. The central progress disclosures give little corresponding outcome evidence, although more detailed records may exist within implementing agencies.

Research from Odisha shows why the duration of paid work requires separate consideration. In an economic assessment unrelated to MISHTI implementation, Jain et al. (2025) estimated that restoring 84 km² of potentially suitable mangrove area could generate approximately 2,200 full-time-equivalent jobs by 2030. This scenario largely involves employment confined to the restoration period; subsequent conservation is frequently assumed to depend on community members who may not be paid. Although these estimates do not

establish actual employment under MISHTI, they identify a structural issue relevant to its design. Even though MISHTI identifies maintenance stages, financing arrangements and responsible agencies, and its convergence guidelines permit wages for eligible maintenance activities (MoEFCC, 2023; MoEFCC & Ministry of Rural Development, 2024), a separate paid-stewardship entitlement is not guaranteed. Moreover, public progress figures do not indicate how much remunerated maintenance work has been delivered.

The social implications extend beyond those directly employed. Mangrove areas are also used for fishing, collection and movement between coastal settlements. If restoration limits access to these activities, established household earnings may decline for longer than the paid planting and maintenance work lasts. Research by Subroto et al. (2026) in India's Sundarbans identifies inequalities associated with forest-access regulations, official procedures and the recognition of customary livelihoods. That study does not attribute these conditions to MISHTI. It nevertheless demonstrates why restoration planning should examine current resource use and the position of households whose incomes depend on it. Consultation, recorded access arrangements and remedies for demonstrated livelihood losses are necessary if additional restoration employment is not to obscure costs imposed elsewhere.

HOUSEHOLD INCOMES AND LOCAL PARTICIPATION

MISHTI's social objectives are not restricted to wage labour. The guidelines permit measures to broaden income sources, training and community tourism involving self-help groups, while state plans are expected to indicate locally relevant support measures (MoEFCC, 2023). In Kendrapara, Odisha, the government reported a five-hectare intervention at Junusnagar near Bhitarkanika and identified proposed activities including duck husbandry, honey production and tailoring in surrounding settlements (MoEFCC, 2025a). The July 2025 statement identifies activities and participating villages, but provides no figures on resulting household earnings. A subsequent parliamentary reply reported that supporting activities were under way from year two, after preparatory work (MoEFCC, 2025b). MISHTI already requires concurrent monitoring of outputs and outcomes (MoEFCC, 2023). Nevertheless, these public disclosures do not establish whether participating enterprises remain viable or how their economic benefits are distributed.

The value of these additional activities rests on their ability to generate earnings after initial assistance ends. Training must correspond to practical production requirements, access to inputs and demand for the goods or services concerned. Equally, equitable benefit distribution cannot be inferred from the participation of self-help groups alone. Information on household earnings, women's control over proceeds and outcomes for resource-dependent residents would permit a more rigorous assessment. These considerations are criteria for evaluation, not documented shortcomings of individual MISHTI enterprises. The publicly available national reports cited here do not provide comparable findings on these matters. Publishing such results would allow participating communities to assess whether the programme is meeting its livelihood objectives.

Community involvement also affects ecological outcomes. Local knowledge can inform site selection, seasonal access and monitoring, while adequately funded stewardship can support the survival of restored vegetation (Sen et al., 2025). The joint convergence guidelines also give Gram Sabhas and Panchayati Raj institutions formal roles in prioritising and approving employment-scheme activities (MoEFCC & Ministry of Rural Development, 2024). However, the national progress figures do not establish how these provisions influence site decisions, resource access or benefit distribution in practice.

POLICY PRIORITIES

MISHTI's existing monitoring arrangements could support clearer reporting of employment and equity outcomes. Site plans should record established occupations, customary access and resource use alongside expected restoration employment. Public reports should distinguish seasonal plantation work from subsequent paid stewardship and identify the authorities responsible for wages, worker protection and grievances. These additions would make labour outcomes more readily verifiable without presuming that existing employment safeguards are being violated.

Livelihood support should be assessed through enterprise continuity, net earnings and the distribution of benefits, alongside participation and training figures. Publicly accessible, site-level results would help communities assess progress and raise concerns about income losses or inequitable access. Where restoration entails verified livelihood costs, responsible agencies should disclose available remedies. Decisions concerning resource use and benefits should

include affected residents, while any future carbon or biodiversity-finance scheme should establish transparent entitlement and payment arrangements before projected revenues are counted as livelihood support (Lo, 2026).

The extension to 2029 offers an opportunity to publish linked ecological and social indicators through MISHTI's established reporting channels. Comparable data on habitat condition, wages actually paid, enterprise earnings and changes in resource access would support independent evaluation. Updated administrative guidance should also clarify convergence with the rural employment legislation that took effect in July 2026 (Ministry of Rural Development, 2026).

CONCLUSION

MISHTI provides for monitoring of both programme outputs and outcomes, annual reporting and independent field assessments (MoEFCC, 2023). However, accessible central government disclosures primarily document restoration areas, expenditure, and proposed activities. They do not yet offer a comparable national picture of employment quality, household income changes, paid stewardship or the distribution of livelihood benefits. This restricts independent appraisal of MISHTI's contribution to a just transition, but does not establish that such information is absent from administrative records or that the activities have failed. The programme is also still under implementation, and its prescribed five-yearly external assessments have a longer evaluation horizon.

This review identifies a gap between the breadth of MISHTI's ecological and socio-economic objectives and the outcomes that can presently be verified from national public information. Disclosing site-level ecological and livelihood findings through the monitoring arrangements already envisaged would strengthen policy scrutiny and enable coastal communities to judge the programme's benefits and costs. Such evidence is necessary to assess not merely whether restoration activities have been funded, but whether they are accompanied by measurable, durable, and equitable economic gains.

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Net Zero Coasts: Integrating Blue Carbon and Climate-Resilient Livelihoods

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The 11,098.81 km-long coastline of India supports ecosystems, jobs, and coastal communities that are facing more pressure from climate change and development. Ports, urbanization, tourism, aquaculture, and industrial growth are reshaping coastal landscapes, while sea-level rise, erosion, cyclones, and salinity intrusion are advancing from the sea. Coastal and marine ecosystems, particularly mangroves, seagrasses, and salt marshes, contribute to climate mitigation by storing large amounts of carbon while supporting fisheries, protecting shorelines, and reducing coastal hazards. Their restoration, however, succeeds only when natural hydrology, sediment processes, and community participation are maintained.

Community-Led Coastal Resilience and Livelihood Systems

Local communities are essential to coastal climate action because they know the land, the water, and the changes that happen over time. Local fishers, farmers, women's self-help groups, and village institutions possess valuable knowledge of shoreline dynamics, seasonal environmental changes, fish breeding grounds, and traditional resource management practices. Experiences from coastal restoration projects indicate that initiatives involving local communities achieve higher levels of stewardship, better ecological outcomes, and greater long-term sustainability.

Evidence from several coastal states shows that ecosystem-based livelihoods can generate both income and environmental benefits. Community-led mangrove restoration in Maharashtra and Gujarat has improved household incomes while reducing cyclone impacts and crop losses. In Odisha's Bhitarkanika and the Sundarbans, healthy mangroves continue to support fisheries, honey collection, and crab harvesting. Seaweed farming is also creating new livelihood opportunities for women and small-scale fishers in several coastal states. These experiences indicate that ecosystem restoration, when well-designed, can deliver livelihood benefits and climate adaptation at the same time.

Sustainable Blue Economy and Climate-Smart Agriculture

India's coastal net-zero pathway hinges on nature-positive livelihoods alongside ecosystem restoration. Sustainable mariculture, seaweed farming, shellfish culture, climate-smart aquaculture, eco-tourism, mangrove-based honey production, and integrated coastal fisheries management can thereby improve community well-being and reduce environmental pressures. Seaweed cultivation, in particular, has demonstrated potential in Tamil Nadu and Gujarat through pilot-scale cultivation for carbon sequestration, nutrient removal, livelihood diversification, and development of bio-based industries.

The agricultural landscapes adjoining India's coasts also have an important role in buffering salinity and stabilizing yields. Coastal agriculture is increasingly affected by salinity intrusion, water scarcity, and extreme weather events. Coastal agriculture can become more climate resilient through salt-tolerant crop varieties, integrated farming systems, agroforestry, improved organic nutrient management, and other locally adapted farming practices. These sectoral interventions require coordinated planning if they are to deliver benefits at scale.

Integrated Coastal Planning for Climate Mitigation and Adaptation

Integrated Coastal Zone Management (ICZM) and Coastal and Marine Spatial Planning (CMSP) provide a practical basis for coordinating these efforts. Effective planning should integrate climate adaptation,

biodiversity conservation, disaster risk reduction, watershed management, fisheries, tourism, infrastructure and blue economy initiatives across sectors. Integrated planning identifies suitable areas for conservation, restoration, sustainable aquaculture, seaweed farming, tourism, and renewable energy while minimizing conflicts and degradation. It also serves as a bridge between mitigation and adaptation. Restoring degraded mangroves and other coastal wetlands enhances carbon sequestration while simultaneously limiting shoreline erosion, reducing flood risks and protecting coastal communities. Promoting sustainable mariculture and climate-smart agriculture in identified coastal stretches can improve livelihoods while reducing environmental impacts.

Net-zero development along India's coast will depend on protecting ecosystems, expanding community-based conservation, promoting sustainable blue economy sectors, and integrating science into coastal planning and decision-making. To achieve this, ICZM and CMSP provide a practical framework for translating these opportunities into measurable environmental and socio-economic benefits. Progress should be tracked using indicators such as the area of mangroves and seagrasses restored, carbon sequestered, shoreline stabilization, fishery productivity, household income, employment generated, and reductions in disaster-related losses.

Sectoral Pathways and Enabling Actions for Net Zero

A few key priority interventions needed to achieve these outcomes are summarized in Table 1. Priority actions include climate-smart and salt-tolerant agriculture, low-input mariculture and seaweed farming, sustainable fisheries, green ports, eco-tourism, mangrove and seagrass restoration, and expansion of offshore wind and coastal solar energy. Better sanitation, wastewater treatment, solid waste management, climate-resilient housing, sustainable transport, and renewable-powered water systems can further reduce emissions while improving coastal environmental quality. Carbon finance and community stewardship can help sustain restoration efforts while creating additional livelihood opportunities.

Many of these interventions have already demonstrated climate benefits and can be scaled through existing coastal development programmes. Climate-smart farming and agroforestry can reduce emissions while increasing soil carbon storage. Mariculture has a substantially lower carbon footprint than conventional freshwater aquaculture. Both onshore and offshore renewable energy planned and implemented with environmental safeguards in the coastal areas can provide large-scale low-carbon power generation. Coastal net-zero strategies must combine emissions reduction with ecosystem conservation and livelihood security, ensuring that economic development remains compatible with the ecological limits of coastal systems. Existing programmes such as ICZM, MISHTI, sustainable beach development, and State Coastal Zone Management Plans already provide entry points for implementing many of these actions. Strengthening coordination among agencies and improving access to climate finance will be essential for scaling them effectively.

Implementation of net-zero interventions along India's coast is constrained by institutional and financial gaps. Mechanisms such as blue carbon crediting, restoration finance, and enabling policies for sustainable aquaculture are still evolving. Coastal management responsibilities are shared among multiple ministries, state departments, and agencies, which can lead to delays in decision-making, fragmented planning, and challenges in long-term monitoring. Strengthening inter-agency coordination, improving access to climate finance, and developing integrated governance mechanisms will be important for scaling up ecosystem restoration and advancing net-zero goals along the coast.

Table 1: Integrating Coastal Sectors for a Net-Zero Pathway on the Indian Coast: Mitigation Actions and Quantified Scope

Sector	Mitigation actions for Indian coast	Quantified scope / data
Agriculture (Salt-tolerant crops, agroforestry, organic nutrient management)	Promote climate-smart coastal farming, salt-tolerant crops (e.g., Salicornia, barley), agroforestry, organic nutrient management, and zero-budget natural farming in salinity-affected zones.	Organic farming systems: 10–30% reduction in CO_2-equivalent emissions relative to conventional systems, depending on crop type and management intensity [1] Organic fertilisers, green manuring, biochar: 5–15% lower GHG emissions and 5–10% increase in SOC [2] Agroforestry on saline soils: 6.84–27.09 Mg C ha^{-1} soil carbon sequestration [3] Biosaline agroforestry soils: 25.9 to 99.3 Mg CO_2 ha^{-1} stored in surface 0.3 m soil [3]. Halophyte cultivation on degraded saline lands: carbon-negative asset via blue carbon sequestration and land reclamation [3].
Mariculture	Scale low-input mariculture, seaweed farming, shellfish culture, and integrated mangrove-aquaculture systems.	Marine aquaculture (mariculture) carbon footprint: ~40% (per unit weight of product) lower than freshwater aquaculture per unit of product [4] Aquatic emissions intensities: >98% lower CH_4 and >80% lower N_2O per kg carcass weight compared to freshwater systems [4]. Seaweed farming and integrated mangrove-aquaculture identified as key coastal livelihood and carbon pathways with low external inputs.
Fisheries	Improve fuel efficiency, cold-chain systems, post-harvest handling, habitat protection, and cooperative fishery management.	Indian marine fisheries: emits about 30% less CO_2-equivalent GHG per kilogram of fish produced compared to the global average [5]. Selective breeding and low-impact gear can reduce emissions intensity documents [5]
Ports	Electrify port operations, expand shore power, improve logistics efficiency, and use renewable energy in port infrastructure.	India's green shipping and port planning documents point to a maritime decarbonization pathway aligned with net zero by 2070.
Tourism	Adopt eco-tourism, waste control, wastewater treatment, carrying-capacity limits, and low-impact shoreline design.	Coastal tourism is part of India's blue economy planning and can be aligned with ecosystem protection and low-carbon development. Sustainable beach tourism in India supports low-carbon development, reduce waste generation, strengthen local livelihoods, and promote economic growth while protecting coastal ecosystems.
Blue carbon	Conserve and restore mangroves, seagrasses, tidal wetlands, and salt marshes; integrate carbon finance and habitat protection.	India's blue carbon stock is estimated at 67.35 Tg C [6]; TERI estimated mangrove standing stock potential at 702.42 Mt CO2e in 2020 and 748.17 Mt CO2e in 2030 [7].

Renewable energy	Deploy offshore wind, coastal solar, and renewable-powered desalination and coastal services.	Blue economy literature highlights offshore wind as a major option; Gujarat and Tamil Nadu together may have ~70–126 GW offshore wind potential [8]. India's national target is 30 GW offshore wind by 2030, with the first 1 GW projects (500 MW each off Gujarat and Tamil Nadu) approved for commissioning by 2028–29 [9].

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