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A DPSIR-Based Evidence-to-Design Framework for Restoration Readiness at Pallikaranai Marshland, Chennai

Prakriti Sudhakar
prakriti.s@alum.cept.ac.in
Independent Researcher
Neena S
Independent Researcher

Research Article

Keywords: Urban wetlands, Ramsar site, Zone of Influence, Wetland governance, Landscape design, Chennai

Posted Date: November 17th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11741380/v1

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Additional Declarations: No competing interests reported.

Abstract

Purpose

Urban coastal wetlands face encroachment, pollution, fragmented governance and disputed boundaries. Pallikaranai Marshland in Chennai, India, a Ramsar site partly under Reserve Forest, is well documented ecologically, yet few studies link this evidence to planning that accounts for legal and spatial uncertainty. This study develops a framework to make that link.

Methods

An evidence-to-design framework was structured around three intervention families: Revive, Restore and Reconnect. Evidence was graded by source type and coded using the Drivers–Pressures–States–Impacts–Responses (DPSIR) framework. An intervention was included only when supported by graded evidence and at least one stated precondition (empirical, legal or safeguard-related). Each intervention was assigned a readiness class and tested under three boundary scenarios: the Reserve Forest limit, an interim Zone of Influence of 128.19 ha proposed in October 2026, and the full Ramsar boundary.

Results

The framework identified six interventions. Hydrological connectivity beyond the Reserve Forest and cross-agency governance depend on the boundary outcome. Most other interventions mainly await baseline surveys. Edge treatments and a pilot removal of *Prosopis juliflora* can proceed within the Reserve Forest, and several interventions keep the same readiness class across all scenarios.

Conclusion

The framework provides a transparent, transferable planning method that distinguishes evidentiary uncertainty from statutory dispute. This allows boundary-independent restoration to begin while legal questions remain unresolved.

1. Introduction

Coastal cities in developing nations are expanding faster than their infrastructure can sustain. They increasingly rely on the natural systems they're consuming. Urban wetlands occupy a paradoxical position: long neglected, they are now recognised as vital ecological infrastructure that provides flood attenuation, water purification, groundwater recharge, and habitat functions critical to coastal cities' resilience (Hettiarachchi et al. 2015). Yet they remain exposed to urban expansion, encroachment, waste dumping, pollution, and fragmented land governance (Hettiarachchi et al. 2015; Coelho 2018). These pressures steadily erode wetland function, even as formal protections like Ramsar designation are extended to them. Across India, wetlands commonly face contested boundaries, incomplete land records, and divided institutional mandates; under these conditions, intervention proves legally complex even where ecological value is clearly established (Coelho 2018; Rosado et al. 2024).

Pallikaranai Marshland, a Ramsar-listed freshwater wetland partly under Reserve Forest in southern Chennai (Fig. 1), exemplifies this tension. Once a far larger contiguous marsh, it has been diminished by decades of urbanisation, solid-waste dumping, and unregulated settlement, attracting sustained scientific, judicial, and administrative attention (Azeez et al. 2007; Ramsar Convention Secretariat and TNSWA 2022; Swetha et al. 2025; TNSWA n.d.). Court-directed management, ecological assessments, and spatial studies have documented the marsh's significance and its degradation (Azeez et al. 2007; Kale and Joshi 2014; Surya 2016; Madhusudhan and Ambujam 2022; Swetha et al. 2025). Recent proceedings on the wetland's buffer zone, including the interim boundary proposed by the Tamil Nadu State Wetlands Authority (TNSWA), show that the boundary question remained legally and spatially unresolved in late 2026 (DT Next Bureau 2026).

Despite substantial existing evidence, studies largely stop short of translating documented ecological conditions into actionable interventions (see Section 1.1). This paper closes the gap by introducing an evidence-to-design framework with three intervention families: Revive, Restore, and Reconnect. By linking documented environmental conditions to targeted interventions, the framework makes each measure's ecological, evidentiary, and legal preconditions explicit. Each intervention is assigned a readiness class indicating what must be in place before implementation.

1.1 Existing research on Pallikaranai Marshland

Research on Pallikaranai Marshland encompasses ecological assessments, management reports, spatial analyses, and restoration proposals (Care Earth Trust 2002; Azeez et al. 2007; Vencatesan 2007; Conservation Authority for Pallikaranai Marsh and Care Earth Trust 2014; Steinbruch and Hörmann 2015; Ramsar Convention Secretariat and TNSWA 2022; Swetha et al. 2025). The only management plan available on the Ramsar Sites Information Service covers the period from 2014 to 2019, prior to the 2022 designation. A revised Integrated Management Plan was still being prepared when the Tribunal decided Original Application No. 91 of 2023 in September 2025 (National Green Tribunal 2025). Azeez et al. (2007) set ecological priorities for the notified Reserve Forest and Raj et al. (2010) compiled a checklist of the marsh's birds. Jayaprakash et al. (2012) reported trace-metal contamination in the nearby Buckingham Canal, while Carver et al. (2015) and Kumar et al. (2014) examined mosquito-borne disease and malaria at the city scale. Kale and Joshi (2014) linked environmental pressures to urbanisation and resource use, and Madhusudhan and Ambujam (2022) analysed land-use change in the marsh and its peri-urban surroundings. These studies document pressures and landscape change but offer little on the workability of specific interventions.

Rosado et al. (2024) applied the Drivers–Pressures–States–Impacts–Responses (DPSIR) framework to Chennai's water system, highlighting institutional friction, while Surya (2016) translated landscape analysis into proposed ecological corridors, drainage improvements, and habitat links. Table 1 compares these studies against the gap between documented degradation and actionable, site-specific restoration.

Table 1
Comparative summary of reviewed Pallikaranai-related studies

Study	Type and scope	Diagnostic basis	Spatial design output	Governance and boundary considerations
Azeez et al. (2007)	Ecological management plan for the Pallikaranai Reserve Forest	Species surveys and assessment of threats to the wetland	Conservation maps and management interventions; limited detail on site designs	Focuses on the notified Reserve Forest boundary; addresses encroachment and boundary protection
Kale and Joshi (2014)	DPSIR case-study chapter; wetland and city scale	Satellite imagery, normalised difference vegetation index (NDVI) and indicators of vegetation, built-up growth and waste dumping (1997–2008)	DPSIR-based spatial and environmental assessment; no detailed physical design proposals	Reviews planning policies and legal responses; does not develop boundary-based design strategies
Surya (2016)	Landscape-ecological design proposal	Land-use and population-density mapping, proximity analysis and ecological assessment	Eco-corridor, drainage improvements, habitat links and recreation areas	Provides limited analysis of land tenure, legal boundaries or court proceedings
Madhusudhan and Ambujam (2022)	Symposium paper; scale of seven peripheral villages	Landsat classification (1988–2020), historical cadastral maps, field observations and interviews	Land-cover and water-body maps; management recommendations	Examines land-use changes and planning history; boundary questions not addressed in design
Rosado et al. (2024)	DPSIR assessment; Chennai metropolitan scale	Environmental indicators covering population growth, land-use change, water resources, pollution and biodiversity	City-scale assessment and policy recommendations; no site-specific design proposals	Identifies fragmented governance, weak law enforcement and coordination gaps; no boundary-based design analysis

Together, these studies establish the ecological, spatial, and governance baselines of Pallikaranai; none systematically link documented conditions to spatial interventions while accounting for evidentiary limits, ecological trade-offs, and legal uncertainty.

2. Methodology

2.1 Research design

The study draws on documentary evidence and previously collected field material to develop a design-reasoning framework; it does not report new field measurements. The field material comes from a 2023 landscape architecture studio project at the marsh (Author 2023), which includes site records, vegetation maps, faunal maps, and a bird-habitat study. The framework consists of five steps (Fig. 2). First, evidence is compiled and graded by source type (E1–E3). Next, the evidence is coded using the DPSIR framework. Then, conditions are translated into potential interventions with a two-criterion rule (Section 2.4). Interventions are classified by readiness and tested against three scenarios (Section 2.5). Finally, the requirements to advance each intervention are identified as unlocking triggers. During manuscript preparation, the authors used an AI-based language tool to assist with restructuring and editing text. The authors reviewed, verified and revised all AI-assisted content and take full responsibility for the content of this manuscript.

2.2 Evidence register and screening protocol

Evidence is collated in a structured register (Online Resource 1, Table S1) and classified by source type. Sources were graded into three classes by the directness of their evidence: E1, primary or official records, such as court and tribunal records, government orders and the Ramsar Information Sheet (Madras High Court 2021; National Green Tribunal 2022, 2025; Ramsar Convention Secretariat and TNSWA 2022; Chennai Metropolitan Development Authority 2025a; TNSWA 2026; TNSWA n.d.); E2, relevant published or secondary evidence, including peer-reviewed studies, institutional reports, management plans and news reports, the last used only for developments not yet available in official records (e.g., Care Earth Trust 2002; Azeez et al. 2007; Conservation Authority for Pallikaranai Marsh and Care Earth Trust 2014; Rosado et al. 2024; Swetha et al. 2025); and E3, prior studio documentation (Author 2023), used only where its observations could be cross-referenced against E1 or E2 evidence or flagged for independent verification. Literature searches covered Scopus, Web of Science, and Google Scholar, alongside university thesis repositories (Online Resource 1, Text S1). Search terms included "Pallikaranai" with wetland-related terms and "DPSIR" with "wetland" and "Chennai". Searches were conducted iteratively over the course of the study and updated up to 22 October 2026 to incorporate ongoing litigation on the wetland's boundary. Retrieved studies, management reports, and legal records were screened for relevance, spatial scale, and evidential support. Records lacking sufficient verifiable evidence were excluded from the analytical matrix. Wetland boundaries were compiled from the Ramsar site boundary (Ramsar Convention Secretariat and TNSWA 2022), the map annexed to the map annexed to the Chennai Metropolitan Development Authority (CMDA) order on the 1 km influence area (Chennai Metropolitan Development Authority 2025a), and the TNSWA interim ZoI map (TNSWA 2026; published in Lakshmi 2026) and were overlaid in a common coordinate system (WGS 84) for comparison. The resulting maps are indicative and were not used to measure areas; all areas reported are official figures.

2.3 DPSIR coding rules

DPSIR is a widely used causal-chain framework for structuring environmental evidence in wetland and coastal systems (Niemeijer and de Groot 2008; Gari et al. 2015; Patrício et al. 2016; El Bahrawy et al. 2017). Each evidence item was coded to one primary DPSIR category. Drivers are socioeconomic, demographic, or institutional forces; pressures are direct stressors; states are physical or biological conditions; impacts are effects on people or biodiversity; and responses are actions by institutions, governments, or communities. Legal and tenure conditions were coded separately as constraints. One researcher coded the evidence items alone, without independent verification or inter-rater reliability assessment.

2.4 Evidence-to-design translation rule

An intervention was included in the evidence-to-design matrix only if two conditions were met: its target condition was documented by at least one E1 or E2 source, and at least one explicit precondition was specified. Preconditions were classified as empirical (surveys or data required before implementation), legal or tenure-related, or safeguard-related (measures to avoid ecological or social harm). Proposals that failed to meet both criteria were excluded. For example, selective excavation (R2) responds to documented loss of marsh extent, but its implementation hinges on a bathymetric survey, sediment-contamination screening, protection of shallow-water foraging habitat, and verification of land tenure. Each intervention is listed separately from the evidence and approvals it requires.

2.5 Readiness classification and unlocking triggers

Each intervention is classified along two axes: spatial tenure and evidentiary support. The spatial axis distinguishes three statutory contexts: the Reserve Forest, where Forest Department records establish tenure; the Ramsar boundary; and the proposed Zone of Influence (ZoI), pending final delineation. The evidence axis distinguishes interventions with adequate supporting data from those requiring site-specific investigation. Together, these produce three readiness classes. Class A (no-regret) interventions lie within the Reserve Forest, are adequately evidenced, and can proceed independently of the ZoI outcome. Class B (survey-first) interventions have secure tenure but require a named survey before implementation. Class C (boundary-contingent) interventions fall within the Ramsar boundary or ZoI or depend on cross-agency cooperation and are restricted until outstanding legal or spatial questions are resolved. Each class has a corresponding unlocking trigger: A Class B intervention moves to Class A when its named survey is complete. A Class C intervention can be reclassified once its boundary is finally delineated or the necessary inter-agency arrangement exists. These conditions are the 'unlocking triggers'. Where the components of a single intervention meet the criteria of different classes but cannot yet be separated spatially, both classes are reported (e.g., A/B), and the lower class applies until the components are separated.

Because the ZoI's boundary awaits judicial determination, each intervention is also classified against three boundary scenarios: S1, the Reserve Forest land held by the Forest Department alone (694.88 ha); S2, the Reserve Forest together with the interim ZoI of 128.19 ha proposed by TNSWA (TNSWA 2026; DT Next Bureau 2026); and S3, the full Ramsar boundary (1,247.54 ha), of which about 550 ha beyond the Reserve Forest is still undergoing delineation (DT Next Bureau 2025). The S1 area is the sum of the four Forest Department parcels recorded in the Madras High Court and National Green Tribunal proceedings; the government states a figure of about 698 ha, and this study uses the parcel total because it can be traced to individual land records (Madras High Court 2021; National Green Tribunal 2022; DT Next Bureau 2025). 'Reserve Forest' means all land held by the Forest Department, although its parcels are at different stages of notification (Section 3.1). Because the ZoI is a buffer around the wetland, not a step between the Reserve Forest and the Ramsar boundary, S1 to S3 are alternative boundary assumptions rather than a strictly nested series. The three boundary scenarios are mapped in Fig. 3, together with the 1 km influence area defined by the Chennai Metropolitan Development Authority (2025a).

Three rules govern classification. First, an intervention drawn across more than one tenure is split into parts that are classified separately and reported separately in the boundary-scenario assessment (Section 4.2); because the studio plan does not locate each part by survey number, the split is an assumption pending verification. Second, a component on land outside a scenario's boundary is marked out of scope for that scenario and is assessed only under a scenario that includes that land. Third, where parcel-level data are insufficient to classify a component, it is marked as not yet assessable; no default class is assigned. This applies to Ramsar-only land under S2, because its overlap with the survey numbers of the interim ZoI has not been established. The framework evaluates data traceability and conditional readiness. It does not verify realised ecological targets or implementation outcomes. Legal and institutional evidence is dated to 22 October 2026, with later orders not reflected. If a future decision adopts one of the three tested boundaries, it selects the corresponding scenario column directly (Section 4.2); a different boundary would be assessed by the same rule.

2.6 Use of prior studio work as a spatial reference

The analysis draws on an earlier landscape architecture studio project on the marsh, completed in 2023 (Author 2023).The project documented site conditions and explored spatial strategies for hydrological restoration, habitat improvement, and public engagement at the Pallikaranai Marshland. The site observations, transects, vegetation, and bird-habitat mapping, edge typologies (Fig. 4), and proposed interventions are used as an existing spatial reference for the DPSIR analysis. These materials are cross-referenced with literature studies, official records, and identified evidence gaps; they are not treated as independent validation of the proposed interventions. The matrix therefore keeps studio proposals separate from independently documented conditions and lists the evidence, permissions, and safeguards each one still needs.

3. Case diagnosis: Pallikaranai Marshland through DPSIR

3.1 Context and Ramsar significance

Pallikaranai Marshland is a freshwater urban wetland with brackish and estuarine conditions on the southern coast of Chennai (Fig. 1). It drains a 250 km² catchment of interconnected wetlands before discharging into the Bay of Bengal through Okkiyam Maduvu and Kovalam Creek (TNSWA n.d.). Historical aerial photographs and Survey of India toposheets from 1965 and 1972 estimate its original extent at approximately 5,500 ha (Vencatesan 2007; National

Green Tribunal 2022; Rosado et al. 2024). After being designated a Ramsar site on 8 April 2022, the wetland's officially listed area is 1,247.54 ha (Ramsar Convention Secretariat and TNSWA 2022; TNSWA n.d.), less than a quarter of its original size. The Forest Department holds 694.88 ha under the Tamil Nadu Forest Act, 1882, in four parcels transferred between 2007 and 2014, now at different stages of notification as Reserve Forest (Madras High Court 2021; National Green Tribunal 2022). The remaining area of about 550 ha is still being delineated (DT Next Bureau 2025).

3.2 DPSIR taxonomy applied to the evidence register

3.2.1 Drivers

Three interacting drivers shape the anthropogenic pressures on Pallikaranai Marshland. Rapid demographic and economic growth have accelerated urbanisation along the Old Mahabalipuram Road (OMR) information technology (IT) corridor on the marsh's eastern edge (TNSWA n.d.; Rosado et al. 2024). In addition, the historical classification of marshland as "wasteland" in revenue records discounted its ecological and hydrological value, facilitating land allocation and reclamation (Care Earth Trust 2002; National Green Tribunal 2022). At the same time, governance is constrained by institutional fragmentation. Despite the dedicated mandates of the Forest Department and the Conservation Authority for Pallikaranai Marsh, limited coordination among regional water management bodies continues to hinder unified conservation (TNSWA n.d.; Conservation Authority for Pallikaranai Marsh and Care Earth Trust 2014; Rosado et al. 2024).

3.2.2 Pressures

The Perungudi dumpsite imposes severe ecological pressure on the marsh. The Greater Chennai Corporation holds a 173.33 ha (428.30-acre) parcel under Patta No. 1012 in Sholinganallur Village. Although waste dumping was historically confined to roughly 81 ha (≈ 200 acres) of this parcel (National Green Tribunal 2022), reports on the biomining initiated in 2021 estimate the affected footprint at approximately 101 ha (≈ 250 acres) (ThePrint 2026). This pressure compounds the hydrological fragmentation caused by the Radial Road, Perumbakkam Main Road, the Mass Rapid Transit System (MRTS), the Velachery–Tambaram Road, and the Inner Ring Road (Author 2023; Fig. 3). Invasive vegetation documented in the studio site analysis adds further ecological pressure (Author 2023). While *Prosopis juliflora* has colonised the marsh margins, the floating macrophyte *Pontederia crassipes* infests open-water zones. The management plan notes large tracts invaded by *Prosopis juliflora* and water hyacinth, with *Prosopis* spreading rapidly along the north-east boundary (Conservation Authority for Pallikaranai Marsh and Care Earth Trust 2014).

3.2.3 States

Research on marshland reveals that urbanisation, sewage discharge, and solid-waste disposal drive chemical and organic pollution. Surface water shows elevated concentrations of metals including lead, chromium and cadmium, with several parameters exceeding regulatory thresholds (Jayaprakash et al. 2010), and water samples collected in September 2022 were assessed for heavy-metal contamination in and around the marsh (Swetha et al. 2025). Assessments in March 2025 linked dissolved solids and organic pollutants to landfill leachate, urban runoff, and sewage overflows during floods (Arjunan et al. 2026). Given differing sampling dates, methods and spatial coverage, these data indicate acute, localised stress, not a uniform or continuously tracked pollution gradient across the marsh.

3.2.4 Impacts

The wetland's flood-attenuation capacity has been compromised by progressive loss and fragmentation; the 2015 Chennai floods demonstrate the consequences of urbanising floodplains and drainage networks (TNSWA n.d.; Selvaraj et al. 2016). Habitat degradation and water pollution threaten the wetland's biodiversity (Rosado et al. 2024), while invasive giant African catfish (*Clarias gariepinus*) compete with piscivorous birds for resources, potentially disrupting the food web (Conservation Authority for Pallikaranai Marsh and Care Earth Trust 2014). Studies in Chennai have examined associations between environmental conditions and malaria prevalence (Kumar et al. 2014; Rosado et al. 2024), but public health outcomes for communities adjoining Pallikaranai are not documented in the sources reviewed. The marsh's marginalisation amidst real-estate expansion highlights the tension between urban growth and recognition of the wetland's ecological and social value (Coelho 2018).

3.2.5 Responses

Following scientific documentation by Care Earth Trust (2002) and local advocacy, 317 ha was notified as Reserve Land by G.O.Ms.No.52 dated 9 April 2007, and later transfers brought the Forest Department's holding to 694.88 ha (Madras High Court 2021; National Green Tribunal 2022). State-led eco-restoration followed, culminating in the 2022 Ramsar designation (TNSWA n.d.). Despite these measures, management and regulatory responses remain incomplete. A Comprehensive Management Plan for 2014–2019 was prepared by Care Earth Trust for the Conservation Authority for Pallikaranai Marsh (Conservation Authority for Pallikaranai Marsh and Care Earth Trust 2014); after the Ramsar designation, the National Centre for Sustainable Coastal Management (NCSCM) began preparing an updated Integrated Management Plan (IMP), and until it is completed, the Tribunal has directed that no approvals that may alter the character of the marshland be granted (National Green Tribunal 2025). The ZoI remains subject to legal challenge and scientific calibration, leaving interim boundaries without final statutory force (TNSWA 2026; CREDAI Chennai v Member Secretary, CMDA 2026).

3.3 Legal and institutional status register

Table 2 summarises the legal and institutional developments affecting development permissions around Pallikaranai Marshland and identifies the evidentiary basis of each entry.

Table 2

Legal and institutional status of Pallikaranai Marshland (as at 22 October 2026)[a]

Date	Event and status
9 April 2007	317 ha notified as Reserve Land under the Tamil Nadu Forest Act, 1882, by G.O. (Ms) No. 52 (National Green Tribunal 2022)
2012–2014	Three further parcels (170.40, 131.55 and 75.93 ha) transferred to the Forest Department, bringing its holding to 694.88 ha; the notification stage differs by parcel (Madras High Court 2021; National Green Tribunal 2022)
10 May 2018	G.O. (Ms) No. 62 reported by the Forest Department to declare marsh parcels Reserve Forest under Section 16; other tables in the same judgment list the 317 ha parcel at the Section 4 stage (National Green Tribunal 2022) [b]
8 April 2022	Pallikaranai Marsh Reserve Forest designated a Ramsar site (Site No. 2481; 1,247.54 ha) (Ramsar Convention Secretariat and TNSWA 2022)
24 September 2025	NGT directs that no approvals that may alter the character of the marshland be granted until the updated IMP, which is to delineate the ZoI, is completed; the 1 km zone is the general ZoI recommended in the earlier management plan (National Green Tribunal 2025)
9 October 2025	CMDA imposes planning restrictions within the Ramsar boundary and a 1 km ZoI, with effect from 6 October 2025 (Office Order No. 07/2025; Chennai Metropolitan Development Authority 2025a)
28 October 2025	State government states that 698 ha is notified Reserve Forest, that about 550 ha of the Ramsar site remains under delineation, and that NCSCM has been entrusted with the IMP and ground-truthing (DT Next Bureau 2025) [c]
February-September 2026	CREDAI Chennai and other developers challenge the restrictions; the Madras High Court directs TNSWA to report on a scientifically informed interim ZoI (CREDAI Chennai v Member Secretary, CMDA 2026; Lakshmi 2026)
9–14 October 2026	TNSWA proposes an interim ZoI of 128.19 ha across 36 survey numbers (TNSWA 2026); the Court adjourns the matter, and the boundary has not received judicial approval (DT Next Bureau 2026)

[a] CMDA, Chennai Metropolitan Development Authority; CREDAI, Confederation of Real Estate Developers' Associations of India; IMP, Integrated Management Plan; NCSCM, National Centre for Sustainable Coastal Management; NGT, National Green Tribunal; TNSWA, Tamil Nadu State Wetlands Authority; ZoI, Zone of Influence

[b] An NGO report gives 697.96 ha as consolidated under this order (Suzhal Arivom 2026); this figure is not corroborated in the NGT judgment

[c] The 698 ha figure differs from the 694.88 ha parcel total used in this study (Section 2.5)

4. Framework application: Revive, Restore, Reconnect

The DPSIR diagnosis is linked to three intervention families, Revive, Restore and Reconnect, drawn from an earlier landscape architecture studio project (Author 2023). Revive targets hydrological function and water retention, Restore addresses faunal habitats and wetland edges, and Reconnect focuses on public access, community relationships, and governance. Figure 4 shows the studio's transects, edge types, vegetation, and bird-habitat mapping used as spatial reference; schematic sections of edge types a–f are given in Online Resource 1 (Fig. S1). Table 3 links each coded condition and its DPSIR tier to supporting evidence, evidence grade (E1–E3; Section 2.2), proposed spatial intervention, studio element, preconditions, and readiness class (Section 2.5). Extending this framework, Table 4 evaluates how these readiness classes perform across the three boundary scenarios. This subdivision reflects differing land statuses and levels of evidential support within a single proposal.

Table 3

Evidence-to-design matrix linking DPSIR conditions to studio interventions, preconditions and readiness class[a]

ID (family)	Documented condition (DPSIR tier)	Evidence and grade	Proposed spatial intervention	Studio-design reference	Preconditions (empirical, legal, safeguard)	Readiness class and unlocking trigger
R1 (Revive)	Hydrological fragmentation and interrupted wetland connectivity (Pressure)	Road and infrastructure pressures on wetland connectivity (Azeez et al. 2007; Rosado et al. 2024) [E2]; roads, institutions and the Perungudi dump described as having altered the marsh's hydrology (Conservation Authority for Pallikaranai Marsh and Care Earth Trust 2014) [E2]; construction and garbage dumping recorded as obstructing the free flow of water, and debris dumped to form a road within the water body (National Green Tribunal 2022) [E1]; channel obstruction and interrupted flow paths identified in the studio site analysis (Author 2023) [E3]	Investigate restoring hydrological connectivity through suitable crossings, culverts or vegetated conveyance channels, and identify whether reconnecting flow paths between the northern and southern sections and towards the Okkiyam Maduvu outlet is possible without transferring polluted water between wetland sections	Transects 2, 3 and 4 (Online Resource 1, Fig. S2)	*Empirical*: catchment-scale hydrological, topographic and water-quality assessment *Legal*: verify tenure and obtain relevant road, rail and landholder permissions *Safeguard*: confirm flow direction, water quality and downstream effects before construction	Class B (part within the Reserve Forest; the part on Ramsar-only land is classified in Table 4) Trigger: completion of hydrological and engineering feasibility studies, pollution screening and field verification
R2 (Revive)	Loss of marsh extent, with an inferred reduction in water-storage capacity, and potential siltation (State/Impact)	Loss of marsh extent from an estimated historical area of about 5,500 ha (Vencatesan 2007) [E2]; (National Green Tribunal 2022) [E1]; the reduction in storage capacity is inferred from this loss rather than measured; siltation at studio-identified sub-areas lacks bathymetric or sediment data (Author 2023) [E3]	Assess selective excavation or basin regrading only where modelling demonstrates a net hydrological benefit, retaining shallow-water shelves and varied water depths instead of uniform deepening	Transect 1 (Online Resource 1, Fig. S2)	*Empirical*: bathymetric survey, sediment-depth mapping and sediment-contamination testing before excavation *Legal*: confirm parcel status and permissions for earthworks *Safeguard*: assess effects on shallow-water foraging habitat, water levels and sediment disposal; specify habitat safeguards	Class B Trigger: completed bathymetric and sediment assessments showing a net hydrological and ecological benefit, and permissions for excavation

ID (family)	Documented condition (DPSIR tier)	Evidence and grade	Proposed spatial intervention	Studio-design reference	Preconditions (empirical, legal, safeguard)	Readiness class and unlocking trigger
R3 (Restore)	Disturbed wetland edges, encroachment and dumping (Pressure/State)	Edge typologies and disturbance patterns recorded in the studio analysis (Author 2023) [E3]; encroachment on Forest Department land, and debris used to fill marshland and form roads, recorded in the Tribunal judgment (National Green Tribunal 2022) [E1]; the Perungudi dump and *Prosopis juliflora* invasion along the north-east boundary, attributed to its waste substrate (Conservation Authority for Pallikaranai Marsh and Care Earth Trust 2014) [E2]. The Forest Department reported no solid waste on its own land in 2019 (National Green Tribunal 2022), so the dumping evidence relates to adjoining land	Test site-appropriate native vegetation buffers and edge treatments, including protective planting where compatible with local ecology and safety	Edge Types a–f (Online Resource 1, Fig. S1)	*Empirical*: site checks of edge conditions and native species at pilot locations *Legal*: confirm land status and permissions *Safeguard*: establish maintenance, waste-control and community-management arrangements	Class A (part within the Reserve Forest; the part on Ramsar-only land is classified in Table 4) Trigger: a small, monitored pilot may proceed on verified sites, subject to site checks, permissions and ecological safeguards
R4 (Restore)	Colonisation by *Prosopis juliflora* and potential displacement of native vegetation (Pressure)	Species occurrence and vegetation patterns identified in the studio analysis (Author 2023) [E3]; invasion of large tracts by *Prosopis juliflora* documented in the management plan (Conservation Authority for Pallikaranai Marsh and Care Earth Trust 2014) [E2]; current distribution and extent need species-level field verification	Phased removal of *Prosopis juliflora*, followed by native vegetation restoration and repeat control where necessary	Vegetation mapping and proposed habitat-restoration zones	*Empirical*: map species distribution and assess soil, hydrology, regeneration and habitat impacts *Legal*: obtain relevant permissions for vegetation removal *Safeguard*: provide follow-up control, restoration and monitoring	Class A (pilot): a limited removal-and-restoration pilot may proceed after species verification, permissions and safeguards Class B (wider implementation). Trigger: vegetation mapping, site assessment and review of pilot monitoring results
R5 (Reconnect)	Enclosure of the marsh by surrounding development, limiting public access and engagement (Impact)	Marsh fragmented into isolated plots hemmed in by housing, commercial development, golf courses and waste dumps, and absorbed into the city's IT-corridor expansion (Coelho 2018) [E2]; limited access points and engagement opportunities identified in the studio analysis (Author 2023) [E3]	Consider carefully located boardwalks, watchtowers and interpretation facilities where they support appropriate access without compromising sensitive habitats	Proposed trails, viewing areas and reclaimed-landfill interpretation centre	*Empirical*: assess bird sensitivity, habitat use, visitor carrying capacity and community needs *Legal*: verify land status, access rights and construction permissions *Safeguard*: develop visitor management, waste control, maintenance and community-engagement arrangements	Class B (trail, viewing and tower components within the Reserve Forest; the Ramsar-only components and the interpretation centre are classified in Table 4) Trigger: ecological and social feasibility assessments, confirmed land and access permissions, and an adopted visitor-management plan

ID (family)	Documented condition (DPSIR tier)	Evidence and grade	Proposed spatial intervention	Studio-design reference	Preconditions (empirical, legal, safeguard)	Readiness class and unlocking trigger
R6 (Reconnect)	Contested jurisdiction and incomplete boundary delineation (Driver/Response)	Tribunal direction linking approvals to completion of the IMP, which is to delineate the ZoI (National Green Tribunal 2025) [E1]; CMDA planning restrictions (Chennai Metropolitan Development Authority 2025a) [E1]; TNSWA interim ZoI proposal of 128.19 ha (TNSWA 2026) [E1], reported as an interim arrangement pending final delineation (DT Next Bureau 2026) [E2]	Establish coordinated wetland and catchment management, with clearly assigned agency responsibilities and a spatially consistent management framework	Proposed governance and management relationships across the wetland and surrounding areas	*Empirical*: reconcile available boundary and spatial records, and complete the scientific and cadastral studies and ground-truthing required for the final ZoI (DT Next Bureau 2026) *Legal*: verify applicable orders, notifications, statutory responsibilities and permissions *Safeguard*: secure inter-agency coordination and clarify responsibility for implementation and monitoring	Class C Trigger: judicial or statutory determination of the ZoI, resolution of outstanding boundary questions, and a formal inter-agency agreement

[a]Evidence grades: E1, primary or official evidence; E2, published or secondary evidence; E3, studio-derived observation or inference requiring independent verification. Preconditions (Section 2.4): empirical, surveys or data required before implementation; legal, tenure or permission requirements; safeguard, measures to avoid ecological or social harm. Readiness classes (Section 2.5): A, no-regret; B, survey-first; C, boundary-contingent. Reserve Forest denotes land under Forest Department control, whatever its notification stage; Ramsar-only land denotes land within the Ramsar boundary outside the Reserve Forest. CMDA, Chennai Metropolitan Development Authority; IMP, Integrated Management Plan; IT, information technology; TNSWA, Tamil Nadu State Wetlands Authority; ZoI, Zone of Influence

4.1 Readiness classes and unlocking triggers

Applying readiness classes to the six interventions in Table 3 separates those that can proceed now from those held back by unresolved legal questions. Interventions R3 and pilot-scale R4 qualify as Class A, proceeding independently of the final ZoI once standard statutory permissions, site access, and an ecologically safeguarded implementation plan are secured. This status indicates boundary independence, not regulatory exemption. Interventions R1, R2, R5, and R4 (at full implementation scale) fall under Class B, which requires the completion and review of baseline hydrological, ecological, or social surveys before implementation begins. Only R6 receives a Class C classification in Table 3, remaining contingent on the legal resolution of the ZoI. Its unlocking triggers include judicial or statutory ZoI determination (via delineation and ground-truthing under the Wetlands (Conservation and Management) Rules, 2017), resolution of residual boundary disputes, and a formal inter-agency agreement. In Table 3, the classes assigned to R1, R3, and R5 are within the Reserve Forest. Their Ramsar-only extensions and R5's interpretation centre are classified separately in Table 4 (Section 4.2).

4.2 Comparison with the studio design and boundary-scenario results

The comparison tests whether the studio's proposed interventions remain implementable once evidential, legal, and safeguard requirements are made explicit, not whether they are ecologically effective. Readiness is further assessed against the three boundary scenarios defined in Section 2.5 (Table 4; Fig. 5).

Table 4
Intervention readiness across boundary scenarios[a]

Intervention	S1 Reserve Forest (694.88 ha)	S2 Reserve Forest + interim ZoI (694.88 + 128.19 ha	S3 Full Ramsar boundary (1,247.54 ha)
R1, within Reserve Forest[b]	B	B	B
R1, Ramsar-only land[c]	Out of scope	Not yet assessable[c]	C
R2	B	B	B
R3, within Reserve Forest[b]	A	A	A
R3, Ramsar-only land[b]	Out of scope	Not yet assessable[c]	C
R4[d]	A/B	A/B	A/B
R5 trails, viewing areas and towers, within Reserve Forest[b]	B	B	B
R5 trails, viewing areas and towers, Ramsar-only land[b]	Out of scope	Not yet assessable[c]	C
R5 interpretation centre, reclaimed dump-yard parcel[e]	Out of scope	Not yet assessable[c]	Not yet assessable
R6	C	C	C

[a] A, no-regret; B, survey-first; C, boundary-contingent. S1 reproduces each component's class in Table 3, assessed against the 694.88 ha of Forest Department land; S2 and S3 test whether that class holds when the assumed boundary changes. Reserve Forest denotes land under Forest Department control, whatever its notification stage; Ramsar-only land denotes land within the Ramsar boundary outside the Reserve Forest. ZoI, Zone of Influence

[b] In the studio master plan, R1 (Transects 2, 3 and 4), R3 (Edge Types a–f) and the trails, viewing areas and towers of R5 are drawn across the whole Ramsar site, so each is split into a part assumed to lie on Forest Department land and a part on Ramsar-only land. The split has not been verified against survey-number boundaries (Section 2.5)

[c] It is not known whether the component overlaps the 36 survey numbers of the interim ZoI

[d] A applies to a limited pilot; B applies to wider implementation pending review of pilot results (Section 2.5)

[e] The reclaimed dump-yard parcel is Greater Chennai Corporation land outside the Forest Department land recorded in the court and Tribunal proceedings; whether it lies within the Ramsar boundary awaits parcel-level confirmation

All six studio interventions meet the translation rule's inclusion criteria (Section 2.4), but none can proceed unconditionally at full scale. The studio design presents each intervention as a single spatial proposal; the framework partitions three by tenure (R1, R3, and R5) and one by phase (R4). This subdivision accounts for variations in land status and evidential support within the same proposal. Only the Reserve Forest part of R3 and the pilot phase of R4 reached Class A.

R2, R4, and R6, along with parts of R1, R3, and R5 within the Reserve Forest, retain the same class across all three scenarios (Table 4). For R2, R4 and these Reserve Forest parts, the preconditions are evidentiary or procedural rather than jurisdictional. R6 remains Class C throughout, addressing the jurisdictional question itself rather than a site defined relative to it. By contrast, the parts of R1, R3 and R5 on Ramsar-only land (R1's ecological connectivity towards Okkiyam Maduvu and between the northern and southern sections, R3's edge treatments beyond the verified pilot sites, and R5's trails and towers beyond the Reserve Forest) fall outside S1, cannot yet be assessed under S2, and are boundary-contingent (Class C) under S3. R5's interpretation centre is proposed on a reclaimed dump-yard parcel, which is Greater Chennai Corporation land, not Forest Department land (National Green Tribunal 2022). The Ramsar-only parts are identified from the studio's spatial reference rather than by survey number, so they indicate where the S1 classes stop applying, not where each intervention will be built.

The stability of R2 and R4 across scenarios reflects the absence of a documented boundary dependency in Table 3, not parcel-level verification against all three boundaries, and the split of R1, R3 and R5 is likewise an assumption. These results should be treated as provisional pending cadastral or spatial verification, rather than as a basis for sequencing implementation.

5. Discussion

By coupling spatial interventions with coded evidence and explicit preconditions, this study operationalises the DPSIR framework for applied urban wetland management. Existing DPSIR studies of Chennai and Pallikaranai Marshland organise environmental evidence and identify policy responses, but they generally stop at diagnosis and recommendation (Kale and Joshi 2014; Rosado et al. 2024). Here, every proposed intervention is anchored by graded evidence and explicit preconditions that are transparent and auditable. This structure allows reviewers and decision-makers to trace the evidence behind

each intervention and scrutinise its prioritisation grading or implementation criteria and identify the empirical and legal preconditions required prior to execution. This approach becomes essential where legal and administrative boundaries remain uncertain. At Pallikaranai Marshland, the spatial extent of regulation remains unresolved (Table 2). Planning restrictions were imposed within a 1 km zone in October 2025 (Chennai Metropolitan Development Authority 2025a; National Green Tribunal 2025), but an interim ZoI of 128.19 ha was proposed in October 2026 while final delineation remained pending (TNSWA 2026; DT Next Bureau 2026). Design proposals that rely on a single, fixed boundary risk becoming outdated.

To manage this uncertainty, the readiness classification assigns interventions to three distinct operational pathways. No-regret measures can proceed independently of the final boundary decision, survey-first interventions await requisite empirical data, and boundary-contingent interventions are reassessed once their unlocking triggers are met. The boundary-scenario analysis demonstrates this practical effect. Inside the Reserve Forest, R1, R3, and R5 sustain their classifications across all scenarios. Their counterparts on Ramsar-only land lie outside S1, are not yet assessed under S2, and become boundary-contingent under S3 (Table 4). This enables structured implementation of boundary-independent components without awaiting full legal resolution, aligning with adaptive and robust planning approaches for deeply uncertain contexts (Hallegatte 2009; Haasnoot et al. 2013). Because each scenario represents a plausible boundary outcome, a future decision that adopts one of the scenarios requires a re-check of classes already tabulated without necessitating a redesign of the interventions.

The analysis also highlights the ecological trade-offs that a solely hydrological design approach might overlook. While water basin deepening (R2) may support hydrological objectives, it may also reduce the shallow-water habitats of wading birds and shorebirds documented at the marsh (Raj et al. 2010). R2 is therefore conditioned on an assessment of effects on shallow-water foraging habitat before implementation (Table 3). These considerations should be treated as testable risk hypotheses rather than demonstrated impacts. Including them in the matrix reveals potential trade-offs early, before management actions are committed. Developed for Pallikaranai, the framework's core – evidence-linked interventions, readiness classification, and trigger-based reassessment – is transferable to other contested ecosystems. Across India and globally, many urban wetlands and Ramsar sites face overlapping tenure, shifting regulations, and uncertain boundaries (Hettiarachchi et al. 2015). In this context, restoration initiatives along the Mula-Mutha rivers in Pune (Dhingra et al. 2023) offer a promising comparative test case. The framework's usefulness beyond the present case has not been tested, and transfer would depend on accessible data, identifiable governance authorities, and legal or planning processes that produce visible triggers for reassessment.

Several limitations must be considered when interpreting the findings. The study relies on secondary data. Although E3 sources cannot serve as the sole basis for including an intervention (Section 2.4), evidence gaps remain. The studio design used as the test case predates the framework, so the matrix tests the readiness of existing proposals rather than generating new ones. The legal review reflects conditions at the cutoff date of 22 October 2026 and does not track later orders, so Tables 2–4 may require updating as judicial and administrative decisions evolve. The 128.19 ha interim ZoI used for S2 is a proposal under consideration by the Madras High Court, not a settled boundary. About 550 ha of the Ramsar area remains undelineated (DT Next Bureau 2025), and the S1 classes have not been verified against the survey-number boundaries of the 694.88 ha of Reserve Forest land. The survey numbers within the Ramsar site were themselves provisional: a provisional list of 304 survey and subdivision numbers, identified by TNSWA and reported to the Tribunal by CMDA in July 2025, was still awaiting verification by the Directorate of Survey and Settlement (Chennai Metropolitan Development Authority 2025b).

The DPSIR framework simplifies non-linear interactions among environmental, social, and governance systems (Niemeijer and de Groot 2008; Patrício et al. 2016), and the qualitative coding was carried out by a single researcher, without secondary verification or inter-rater reliability testing. Ecological factors such as bird habitat function as preliminary screening criteria rather than measured outcomes, while the scenario results remain provisional as outlined in Section 4.2.

These limitations outline a concrete agenda for future research. Priority should be given to independent study of the intervention matrix by a cross-disciplinary panel of landscape architects, wetland ecologists, public health experts, and planners. Field studies are needed to test key assumptions, particularly the relationship between water depth and waterbird guild use, and mosquito-borne disease risks at settlement-facing wetland edges (Carver et al. 2015). Testing the framework in other contested urban wetlands would clarify its usability and offer an empirical foundation to evaluate decision-support tools amid ecological and regulatory uncertainty.

6. Conclusion

This paper applies a DPSIR diagnosis to spatial design through a traceable framework that maps direct decision dependencies. The framework uses a two-criterion translation rule, where each intervention addresses empirically documented conditions and specifies preconditions. Its readiness classes distinguish interventions that can proceed independently from those that await a survey or a legal and institutional trigger, and a boundary-scenario analysis tests whether these classes hold under jurisdictional uncertainty. Applied to Pallikaranai Marshland, the framework yields six interventions across three families. Extending hydrological connectivity into Ramsar-designated lands outside the Reserve Forest (R1) and establishing cross-agency governance (R6) remain boundary-contingent, as their underlying land tenure and Zone of Influence (ZoI) boundaries are unresolved. By contrast, other measures are constrained by survey requirements, while edge treatments (R3) and a pilot removal of *Prosopis juliflora* (R4) can proceed within the Reserve Forest. This distinction represents a design outcome, not an analytical caveat. The proposed framework is methodological, making design reasoning auditable where legal and spatial boundaries remain unsettled. This very condition is common in many urban wetlands in emerging cities. For Pallikaranai, it separates interventions that can begin once permissions and safeguards are in place from those that must wait for further surveys or regulatory change.

Declarations

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Author Contribution

P.S. conceived and designed the study, developed the studio project on which the analysis draws, carried out the evidence compilation, DPSIR coding and readiness analysis, prepared the maps and figures, and wrote the first draft of the manuscript. N.S. critically reviewed the manuscript, rewrote and edited sections of the text, and carried out language and grammar editing. Both authors commented on previous versions of the manuscript and read and approved the final manuscript.

Acknowledgement

The authors thank the faculty who guided the studio project on which this study builds, and the officers of the Tamil Nadu Forest Department and the local community for their support during field study.

Data Availability

The data analysed during this study are from published articles, reports, court records, official documents and an online studio portfolio (Author 2023), all cited in the reference list. The legal status register, the evidence-to-design matrix and the boundary-scenario assessment generated during the study are included in this article (Tables 2–4), and the maps (Figs. 1, 3 and 5) were prepared from the cited sources. The evidence register and search details supporting this study are provided in Online Resource 1.

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Figures

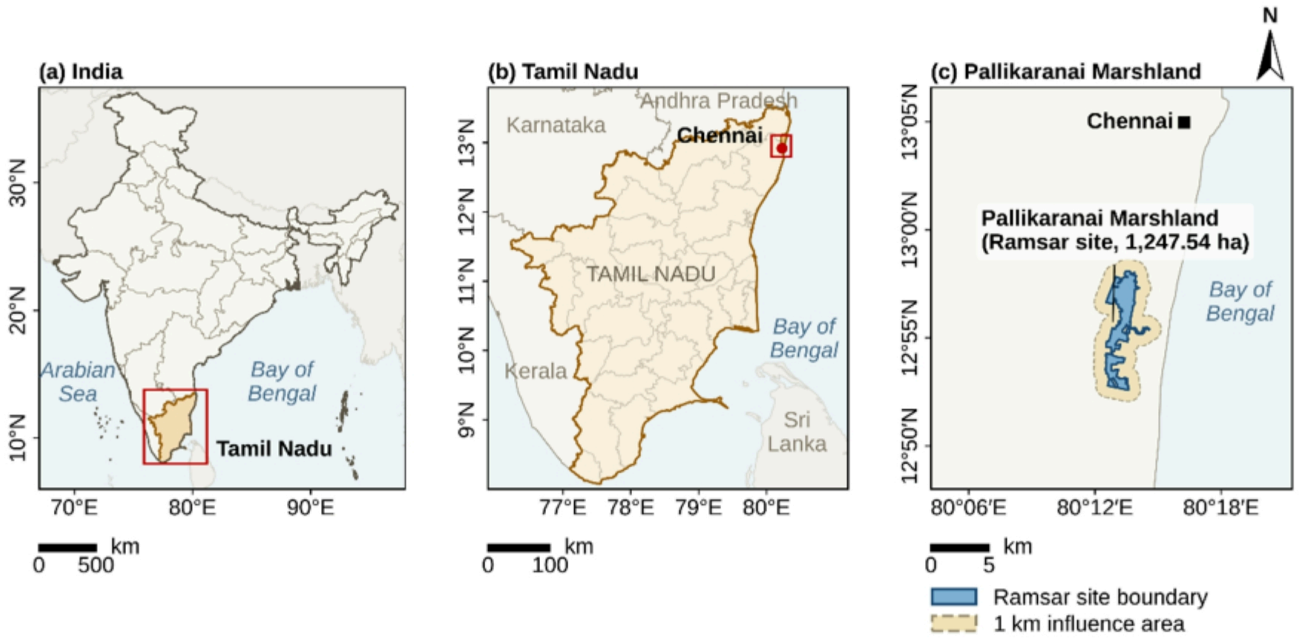


Figure 1

Study area and geographical context of Pallikaranai Marshland, Chennai, India: (a) India; (b) Tamil Nadu; and (c) Ramsar site boundary and 1 km influence area. Source: Authors' compilation using the Ramsar site boundary shapefile from the Ramsar Sites Information Service (Ramsar Convention Secretariat and TNSWA 2022), Census of India 2011 administrative boundaries (DataMeet n.d.), and the 1-km influence area defined by Chennai Metropolitan Development Authority (2025a)

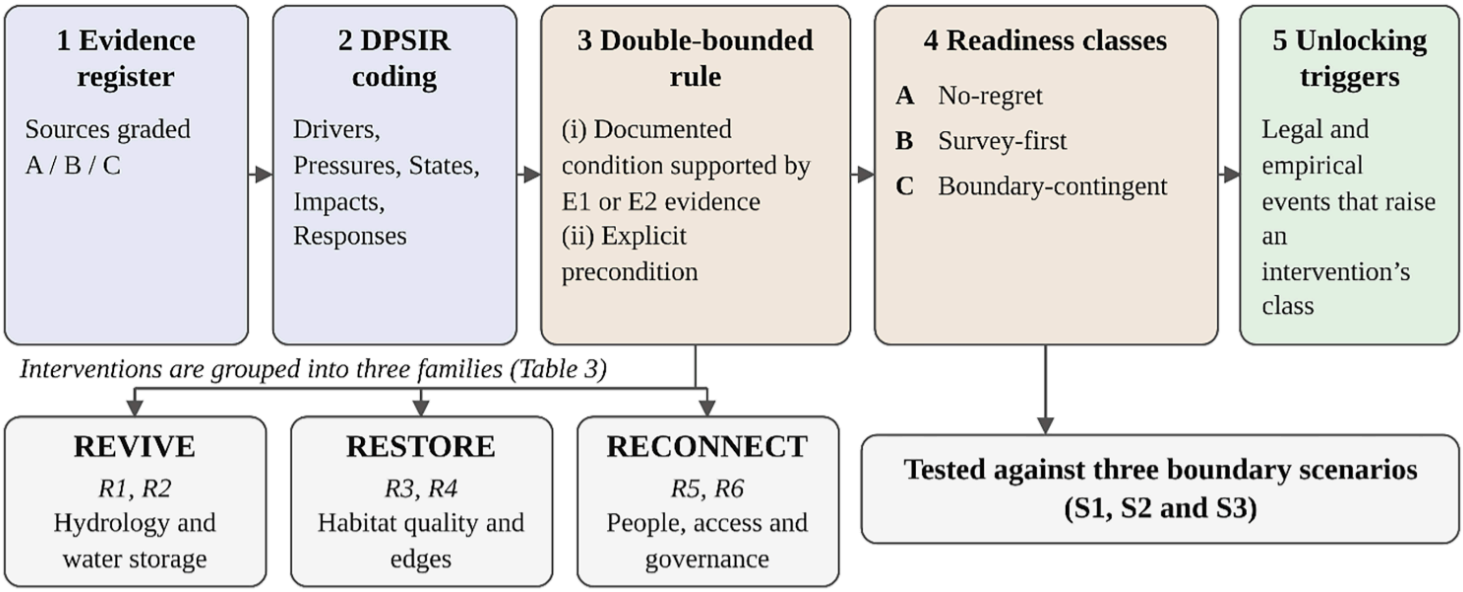


Figure 2

Five sequential steps of the evidence-to-design framework. Source: Authors

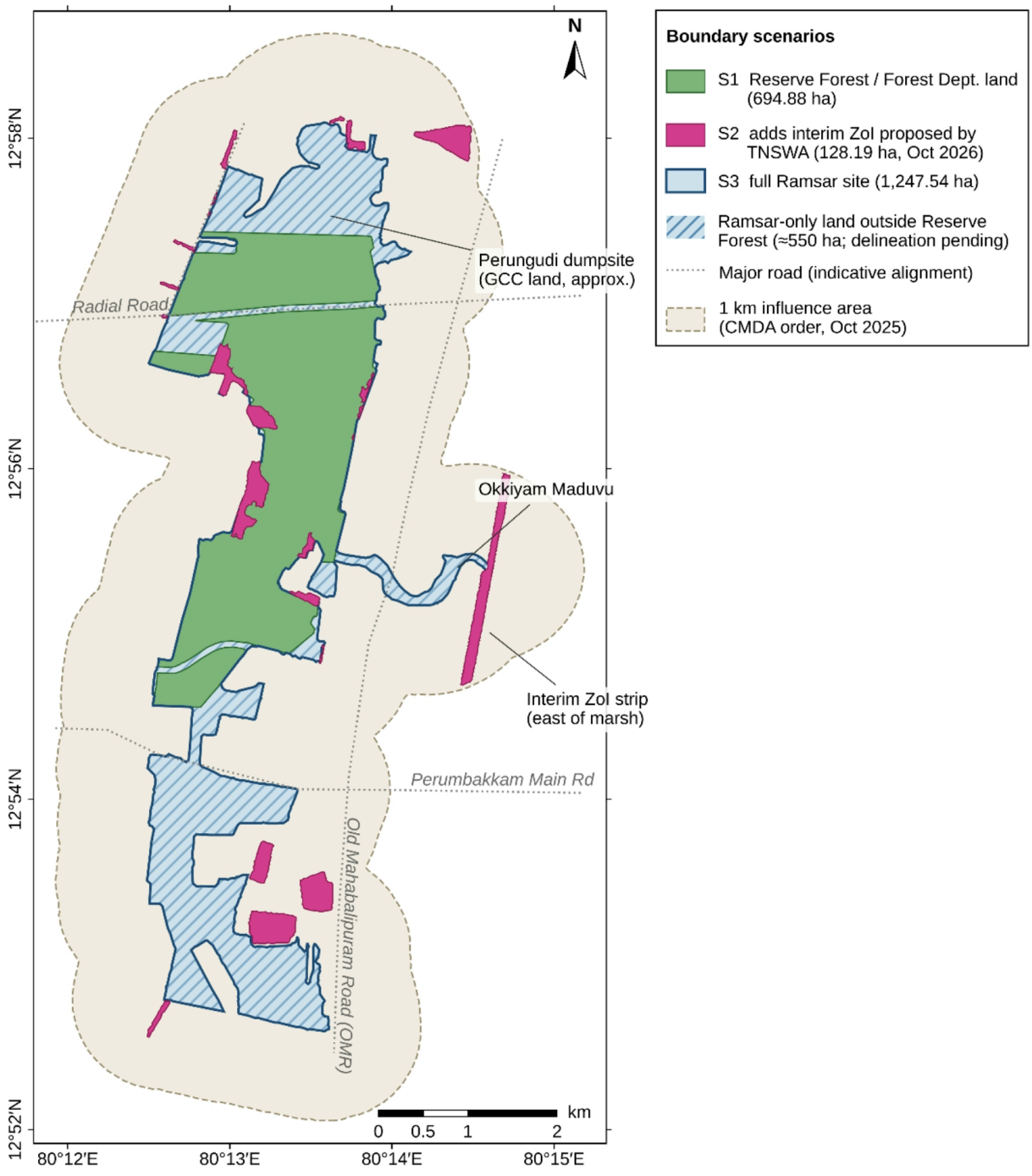


Figure 3

Boundary scenarios S1–S3, showing the 1 km influence area and indicative road alignments. Source: Authors' compilation. The Ramsar boundary is from the Ramsar Sites Information Service (Site No. 2481; Ramsar Convention Secretariat and TNSWA 2022). S1 (Pallikaranai Swamp Area, treated here as Forest Department land) and the 1 km influence area were traced from Chennai Metropolitan Development Authority (2025a). Interim ZoI parcels were traced from TNSWA's map reproduced in Lakshmi (2026). The Perungudi dumpsite location is approximate; road alignments are schematic, based on Google Earth imagery. All mapped extents are indicative and not for cadastral use

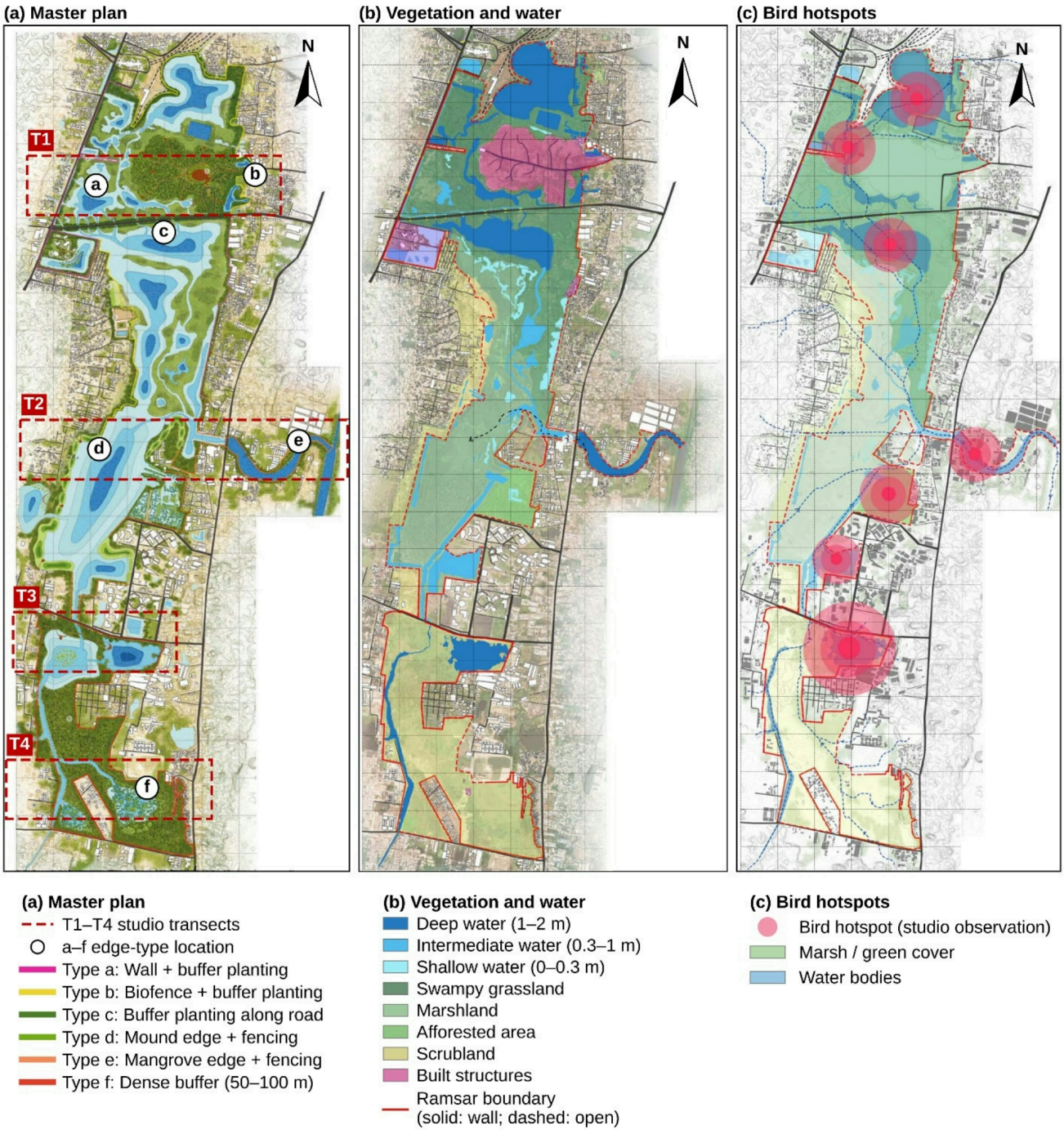


Figure 4

Studio site analysis used as the spatial reference: (a) master plan with transects T1–T4 and edge types a–f; (b) vegetation and water depth; (c) bird hotspots. Edge-type markers a–f indicate representative locations. Source: Author (2023); panels (b) and (c) were redrawn by the authors based on data in Conservation Authority for Pallikaranai Marsh and Care Earth Trust (2014)

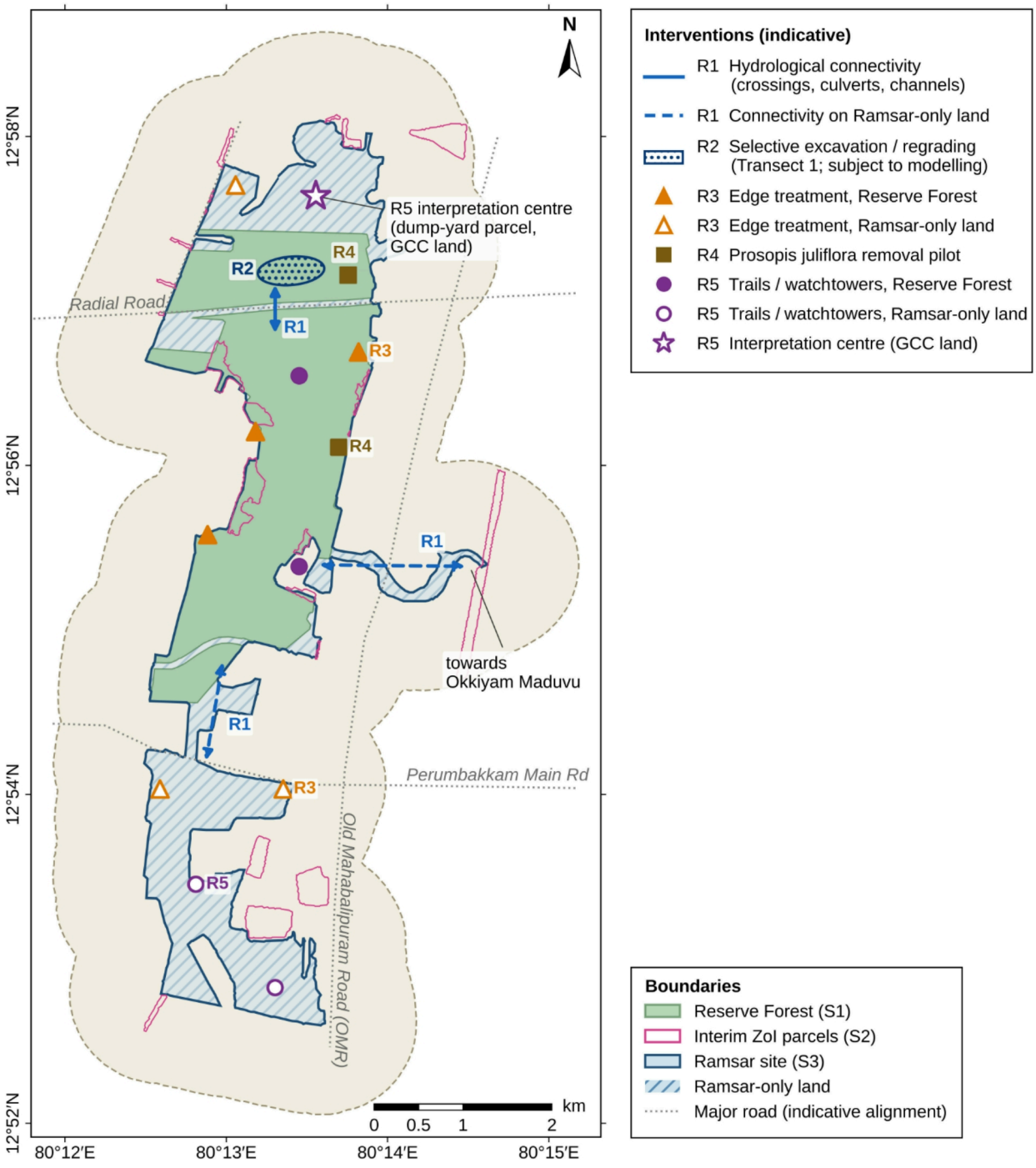


Figure 5

Indicative locations of interventions R1–R5 across boundary scenarios. Filled symbols indicate Reserve Forest locations (Table 3); open symbols indicate Ramsar-only or Greater Chennai Corporation land (Table 4). Source: Authors' compilation; locations are schematic, based on the studio master plan and transects (Author 2023) and the Comprehensive Management Plan (Conservation Authority for Pallikaranai Marsh and Care Earth Trust 2014). R6 (cross-agency governance) applies site-wide and is not mapped. Boundaries as in Fig. 3; the interpretation centre's position relative to the Ramsar boundary remains unconfirmed (Section 4.2)

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx
- Table2.docx
- Table3.docx
- Table4.docx
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