Bridging Knowledge and Action for Regenerative Systems:

Application of GIS-Enabled Environmental Knowledge for Tree, Mangrove and Coral Restoration

Sawsan Zaater, 2026

ABSTRACT

Regenerative environmental systems rely on understanding the interconnections between ecological, social, and economic components. Cross disciplinary collaboration and systems thinking enable stakeholders to move beyond isolated environmental issues and address long-term ecological patterns and impacts, resulting in more effective, resilient, and sustainable interventions

This paper demonstrates how Red Sea Global (RSG) as a developer applies Geographic Information Systems (GIS) to maintain the connection between Environmental Social Impact Assessments (ESIA) findings and environmental management throughout the project lifecycle across three interconnected ecosystems within AMAALA: terrestrial vegetation, coastal mangroves, and coral reef habitats.

Building on ESIA principles, RSG has embedded an integrated GIS-enabled approach that maintains environmental information through planning, design, construction, restoration, monitoring, and continued environmental management. This ensures that environmental data generated through impact assessment remains an active decision-support resource, enabling informed, evidence-based decision making throughout the project lifecycle.

Central to this approach is cross-departmental collaboration between environmental planning, assessment, compliance, engagement, GIS specialists, consultants, and Subject Matter Experts (SME's). Integrating diverse ecological datasets with multidisciplinary expertise strengthens the application of the mitigation hierarchy by supporting the identification of appropriate mitigation measures, restoration and rehabilitation opportunities, and adaptive environmental management actions.

This collaborative process enables projects to enhance ecosystem function and resilience, by enabling restoration and rehabilitation initiatives that create opportunities for long-term regenerative environmental outcomes.

*Corresponding Lead Author: Sawsan Zaater

1. INTRODUCTION

Environmental and Social Impact Assessments (ESIAs) generate extensive environmental baseline information that underpins project planning, environmental decision-making, and regulatory compliance. Beyond supporting project approvals, these datasets represent a valuable source of environmental knowledge that continues to inform mitigation, restoration, rehabilitation, and long-term environmental management throughout the project lifecycle. Maximizing this value of the ESIA requires environmental information to remain accessible, integrated, and consistently applied as projects progress from planning and design through construction, operation, monitoring and continual improvement of environmental management throughout the project lifecycle.

Maintaining this continuity presents a practical challenge. Environmental information is typically generated across multiple technical disciplines, specialist studies and project phases, often resulting in fragmented datasets that can become disconnected from subsequent project decisions. As projects evolve, opportunities to strengthen mitigation, restoration, rehabilitation, and ecosystem enhancement depend on preserving environmental information and ensuring it remains connected to planning, design, construction, compliance, monitoring, and operational activities through effective cross-disciplinary collaboration.

To address this challenge, Red Sea Global (RSG) has embedded ESIA-derived environmental information within a centralized GIS Environmental Catalogue across the AMAALA development - a regenerative tourism destination on the northwestern coast of the Kingdom of Saudi Arabia covering approximately 4,200 km^2 of environmentally diverse terrestrial, coastal, and marine habitats.

Rather than functioning solely as a repository of environmental data, the GIS platform enables environmental information to be maintained, integrated, and collaboratively applied across multiple disciplines throughout the project lifecycle, supporting a Measure, Map and Target (MMT) workflow, as illustrated in Figure 1.

Baseline information generated through environmental surveys is first *measured* to characterize ecosystem condition and ecological attributes, including species composition, abundance, habitat condition, and environmental sensitivities. The assessed information is then *mapped* within the GIS Environmental Catalogue, where ecological, spatial, and project datasets are integrated into a centralized evidence base. Through multidisciplinary collaboration, SME's subsequently *target* appropriate mitigation measures, restoration priorities, rehabilitation initiatives, and, where appropriate, regenerative environmental opportunities by applying the mitigation hierarchy throughout the project lifecycle

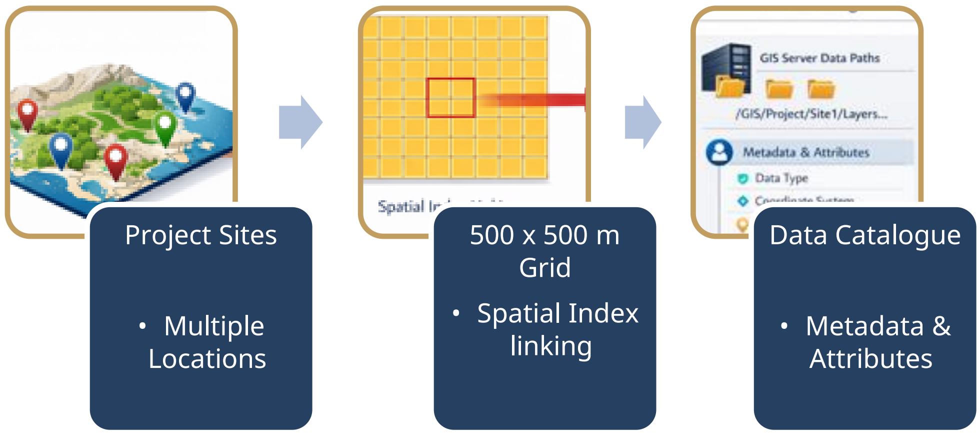

Figure 1: GIS-Enabled Knowledge Framework Supporting the Measure Map Target Workflow

The GIS-enabled MMT workflow provides the operational mechanism through which ESIA derived environmental information is translated into practical environmental management actions. This workflow aligns with RSG Survey, Identify, Intervene and Gain (SIIG) model revealed by (RSG)[1], as shown in Figure 2, which provides the broader regenerative framework for delivering measurable ecological outcomes.

Within the SIIG model, comprehensive environmental surveys establish an understanding of ecosystem conditions, while integrated GIS datasets support the identification of ecological pressures, environmental sensitivities, and restoration opportunities. The evidence generated through the MMT workflow enables multidisciplinary teams to design and implement appropriate mitigation, restoration, rehabilitation, and enhancement initiatives, with subsequent monitoring could provide measurable indicators of ecosystem recovery and environmental performance. Together, the GIS Environmental Catalogue and the SIIG model ensure that environmental information remains an active decision-support resource throughout the project lifecycle, enabling

[1] **Red Sea Global (RSG)** (2025). *SIIG model* (internal investment and sustainability framework). Red Sea Global, Saudi Arabia.

environmental management to evolve beyond regulatory compliance toward long-term ecosystem resilience and regenerative environmental outcomes.

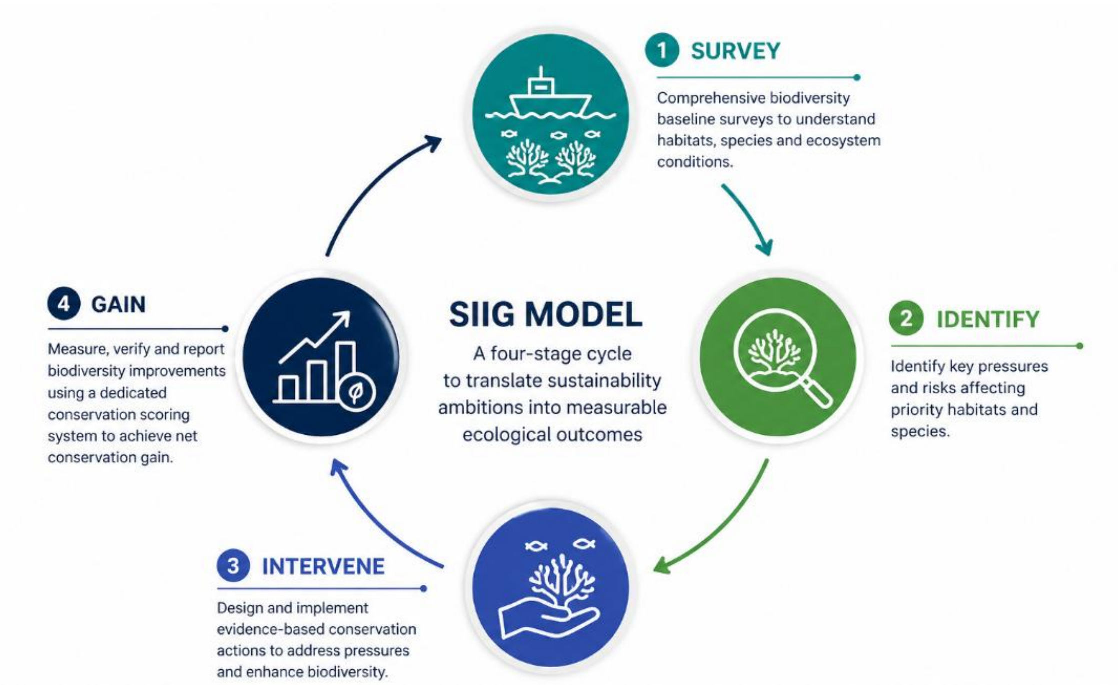

Figure 2: The Four Stage SIIG Model Methodological Framework

The practical application of this integrated framework (GIS-enabled MMT workflow and SIIG model) is demonstrated across interconnected terrestrial, coastal, and marine ecosystems within AMAALA. The following section illustrates how ESIA-derived environmental information is measured, mapped, and collaboratively applied across each ecosystem to support mitigation, restoration, rehabilitation, and adaptive environmental management while recognising the ecological connectivity between terrestrial, coastal, and marine environments.

2. APPLICATIONS ACROSS INTERCONNECTED ECOSYSTEMS

The practical application of this framework is demonstrated across interconnected terrestrial, coastal, and marine ecosystems within AMAALA. These applications illustrate how a consistent GIS-enabled MMT workflow can be applied across different ecological environments while recognising the ecological connectivity between them.

Within the terrestrial ecosystem, the framework utilized tree survey data collected across AMAALA between 2023 and 2025. The surveys recorded standardized ecological and spatial attributes, including species, geographic location, habitat type, tree size, health, structural condition, native or non-native classification, recommended management actions, and associated survey metadata. Beyond quantifying tree loss, these attributes provide the environmental context needed to understand vegetation within its surrounding habitat, enabling the integration of tree data with broader ecological datasets to support habitat-based mitigation, restoration, and landscape scale environmental management.

The coastal application demonstrates how ESIA derived mangrove and terrestrial vegetation assessment data were integrated within the GIS Environmental Catalogue to support ecosystem-based restoration planning. Baseline surveys identified 110 affected mangrove plants across nine assessment plots, while terrestrial vegetation survey data from the adjacent terrestrial environment was incorporated into the same spatial assessment where both ecosystems occurred within the project footprint. Each record captured standardized ecological and spatial attributes, including species or life form, plant size, health, habitat, location, and impact status, providing a comprehensive representation of the coastal environment as shown in Figure 3.

Figure 3: Terrestrial Habitats and Mangrove Distribution

By integrating mangrove and adjacent terrestrial vegetation datasets with hydrological, shoreline, sediment, and tidal information, the GIS Environmental Catalogue provides a comprehensive understanding of the wider coastal ecosystem. This integrated evidence base can support multidisciplinary teams in evaluating habitat connectivity, ecosystem condition, and future restoration opportunities across interconnected habitats. Rather than considering mangrove and terrestrial vegetation independently, the framework enables restoration planning to incorporate the ecological relationships between both ecosystems, supporting future mitigation and restoration measures that enhance tidal function, habitat connectivity, and long-term ecosystem resilience.

Within the marine ecosystem, coral reef survey data were integrated with spatial analysis to support coral mitigation, restoration, and long-term environmental management. Baseline surveys characterized coral species, colony condition, habitat attributes, and environmental sensitivities, with the integrated spatial information providing an evidence base for restoration planning, implementation, and long-term monitoring. This included coral relocation where appropriate, nursery propagation, out-planting initiatives, and monitoring of coral health, growth, survival, recruitment, and associated marine communities, contributing to the long-term resilience of coral reef ecosystems.

Collectively, these ecosystem applications demonstrate that maintaining ESIA-derived environmental information within a centralized GIS environmental platform enables multidisciplinary teams to apply a consistent MMT workflow across diverse yet interconnected ecosystems. This supports the implementation of context specific mitigation, restoration, rehabilitation, and adaptive environmental management throughout the project lifecycle while contributing to resilient ecosystems and, where appropriate, long-term regenerative environmental outcomes.

3. ROLE OF COMMUNICATION AND CROSS DISCIPLINARY COLLABORATION

The long-term value of ESIA depends on environmental information being effectively communicated, shared, and applied throughout the project lifecycle. By maintaining collaboration between project disciplines, ESIA-derived information evolves from a reporting requirement into a shared environmental evidence base that supports informed decision-making across planning, design, construction, operation, and environmental management.

A centralized GIS environmental platform provides a single source of environmental information that enables environmental planners, impact assessment specialists, GIS professionals, engineers, restoration specialists, contractors, environmental compliance teams, and operational managers to work from a common environmental evidence base. This improves consistency, transparency, and coordination while maintaining the connection between baseline environmental information and subsequent project activities.

By strengthening communication and cross-disciplinary collaboration, ESIA-derived environmental information becomes an active decision support resource rather than a project deliverable. This enables multidisciplinary teams to consistently apply environmental knowledge when implementing mitigation, restoration, rehabilitation, compliance, and long-term environmental management throughout the project lifecycle.

4. DISCUSSION

Environmental assessments generate valuable environmental knowledge that supports project planning, impact assessment, and regulatory approval. However, as projects progress through planning, design, construction, operation, and monitoring, environmental information is often dispersed across technical reports, project teams, and project phases, limiting its continued application to environmental decision-making throughout the project lifecycle.

The applications presented in this study demonstrate that maintaining ESIA-derived environmental information within a centralized GIS Environmental Catalogue enables environmental knowledge to remain available beyond the assessment stage. The approach builds on existing ESIA principles and strengthens implementation of the mitigation hierarchy by allowing multidisciplinary teams to consistently apply the same environmental information when identifying mitigation, restoration, rehabilitation, monitoring, and adaptive environmental management actions.

Maintaining a common environmental evidence base is particularly valuable where environmental decisions are shared across multiple disciplines. By enabling environmental planners, engineers, GIS specialists, environmental professionals and operators work from the same environmental evidence base, ecological considerations can be incorporated earlier and more consistently throughout project planning and delivery. This supports a more integrated approach to environmental management by considering ecological connectivity, cumulative impacts, and long-term ecosystem function alongside engineering and operational requirements.

Together, the GIS-enabled MMT workflow and RSG SIIG model provide complementary operational and strategic mechanisms for maintaining environmental information throughout the project lifecycle. While the MMT workflow provides the practical process for preserving, integrating, and applying ESIA-derived information, the SIIG model provides the broader regenerative framework through which this information can inform restoration, rehabilitation, adaptive environmental management, and long-term environmental stewardship.

The findings demonstrate that regenerative environmental outcomes do not require a separate assessment methodology but can emerge through the continued preservation, integration, and collaborative application of existing ESIA-derived environmental information. Extending the value of environmental assessment beyond regulatory approval enables projects to strengthen environmental stewardship throughout their lifecycle, supporting resilient ecosystems and identifying opportunities for restoration and regeneration where appropriate.

5. CONCLUSION

This paper demonstrates that the long-term value of ESIA lies not only in supporting planning decisions and regulatory approval but also in preserving environmental knowledge as a continuous decision-support resource throughout the project lifecycle. By maintaining ESIA-derived environmental information within a centralized GIS Environmental Catalogue and enabling its collaborative application across multidisciplinary teams, environmental information can continue to inform mitigation, restoration, rehabilitation, monitoring, and adaptive environmental management as projects evolve.

By extending the value of ESIA thought out the project phases, environmental assessment becomes not only a tool for identifying impacts, but a foundation for informed environmental stewardship throughout the project lifecycle.

REFERENCES

Duguma, L., Minang, P., Betremariam, E., Carsan, S., Nzyoka, J., Bah, A. and Jannadass, R., 2020. *From Tree Planting to Tree Growing: Rethinking Ecosystem Restoration Through Trees*. ICRAF Working Paper No. 304. Nairobi: World Agroforestry. https://doi.org/10.1016/j.ecoleng.2025.107520

Klein, W. (2024). Restoring mangrove ecosystems: Strategies for conservation and sustainability. *Journal of Marine Science: Research & Development, 14*(6). https://doi.org/[DOI]

Winterwerp, J. C., Bayney, A., Engel, S., Jack, L., Moseley, K., & Smits, B. (2025). Mangrove recovery by habitat restoration using nature-based solutions. *Ecological Engineering, 212*, 107520. https://doi.org/10.1016/j.ecoleng.2025.107520

Sitthi, A., Pimple, U., Piponiot, C., & Gond, V. (Year). Assessing the effectiveness of mangrove rehabilitation using above-ground biomass and structural diversity. *Scientific Reports, Volume*, Article number. | https://doi.org/10.1038/s41598-025-92514-7

Buro Happold & Five Oceans Environmental Services LLC. (2021). *TRSDC AMAALA Biodiversity Action Plan* (Version 1, Report No. 1RI90903-903D04-BHD-RPT-EN-0021). Prepared for The Red Sea Development Company.

Beeston, M., Cameron, C., Hagger, V., Howard, J., Lovelock, C., Sippo, J., Tonneijk, F., van Bijsterveldt, C. and van Eijk, P. (Editors) 2023. Best practice guidelines for mangrove restoration.