Incorporating Environmental Safeguards in Mangrove Habitats

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Abstract

Coastal infrastructure development within mangrove ecosystems requires a balance between project delivery and the protection of sensitive ecological receptors. This paper presents a case study from the AMAALA destination on the Red Sea coast of Saudi Arabia, where environmental safeguards were integrated into the design of a boardwalk crossing an *Avicennia marina* mangrove habitat associated with the Six Senses Resort development.

The project applied a structured approach involving ecological baseline surveys, spatial mapping, impact assessment, regulatory alignment, design refinement, contractor-level environmental controls, and construction-phase monitoring. Survey findings were incorporated directly into engineering decisions, allowing the project team to optimize the boardwalk alignment and adopt an elevated pile-supported structure with micro-sited foundations.

The revised design reduced estimated direct impacts from 110 mangrove individuals under the initial design to 37 under the final modified design, representing an approximate 66% reduction in predicted vegetation impact. In parallel, enhancement planning identified suitable areas for approximately 3,450 mangrove seedlings, with 3,483 seedlings ultimately recorded as planted in the enhancement implementation data, supporting long-term ecological resilience.

The case demonstrates that environmental safeguards are most effective when introduced early enough to influence design decisions rather than being applied only as post-design compliance measures. It provides a transferable example of how impact assessment, environmental compliance, and engineering design can work together to reduce ecological impacts in sensitive coastal environments.

1. Introduction

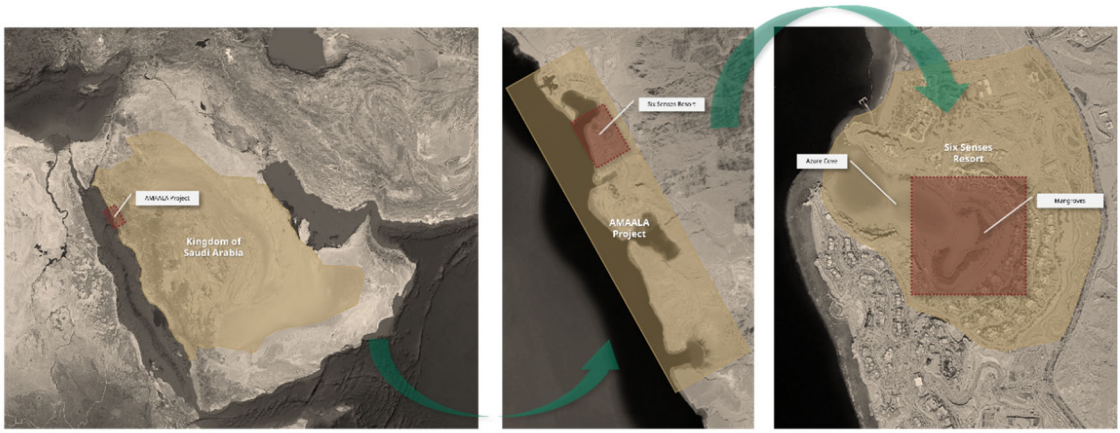
Mangrove ecosystems provide important ecological services, including shoreline stabilization, sediment regulation, biodiversity support, nursery habitat for marine organisms, and long-term carbon storage. These functions make mangroves valuable coastal receptors, but also sensitive to physical disturbance, particularly where construction activities may affect substrate conditions, tidal exchange, root-zone integrity, and sediment dynamics.

Coastal development often occurs in the same locations where mangroves provide their greatest ecological value: sheltered shorelines, shallow coastal waters, tidal zones, and intertidal sediments. This creates a practical challenge for impact assessment and project delivery. The question is not only whether development can proceed, but how environmental information can be used early enough to shape better project decisions.

This paper presents a case study from the AMAALA destination in north-western Saudi Arabia, where a proposed boardwalk associated with the Six Senses Resort intersected a mangrove-lined lagoon within the Azure Cove area. Rather than treating environmental compliance as a final approval checkpoint, ecological information was used as a design input to reduce impacts before construction.

The objective of this paper is to demonstrate how early ecological integration, evidence-based design refinement, and structured compliance frameworks can reduce impacts on sensitive mangrove habitats while supporting responsible coastal infrastructure delivery.

Figure 1. Location of mangrove stand in relation to AMAALA destination and Saudi Arabia



2. Project and Regulatory Context

The project is located within the AMAALA destination along the Red Sea coast of Saudi Arabia. The case study area consists of a compact but ecologically important mangrove stand dominated by *Avicennia marina*, commonly known as grey mangrove. Environmental management for the project was undertaken within the Saudi national environmental regulatory framework, including the Environmental Law issued under Royal Decree M/165 and associated permitting requirements administered through relevant national environmental authorities. These include the Ministry of Environment, Water and Agriculture, the National Center for Environmental Compliance, and the National Center for Vegetation Cover and Combating Desertification.

At project level, these obligations were incorporated through environmental assessments, permit conditions, management plans, contractor requirements, and stage-gate reviews across the project lifecycle. The compliance approach was therefore not limited to administrative permitting. It was translated into practical design constraints, construction controls, monitoring requirements, and contractor obligations.

In this case, the environmental process helped convert ecological survey findings into design decisions and design decisions into construction-phase safeguards.

3. Ecological Assessment and Design Integration

A detailed mangrove vegetation survey was conducted during February and March 2024 to support assessment of the proposed boardwalk. The survey used a plot-based approach informed by previous Red Sea project methodologies and established mangrove survey techniques. Nine vegetation plots measuring 10 m × 10 m were established across the project footprint, representing a total surveyed plot area of 900 m². Survey activities included vegetation classification, habitat characterization, field observations, and GPS-referenced spatial mapping.

The survey recorded 325 mangrove individuals across multiple growth classes, including seedlings, saplings, small trees, and mature trees. Plant density ranged from 14 to 66 individuals per 100 m², demonstrating spatial variability across the lagoon habitat. The habitat also contained well-developed pneumatophore networks and evidence of biological activity within the mangrove substrate.

These findings confirmed that the area was not simply an isolated vegetation patch. It was a functioning mangrove habitat with ecological features requiring careful design consideration. GPS-referenced field data were incorporated into spatial mapping to identify the relationship between the proposed boardwalk alignment and sensitive mangrove features. This included mature trees, dense root-zone areas, and areas of higher vegetation density. The spatial outputs allowed the project team to move from general environmental awareness to site-specific design decision-making.

4. Design Optimization and Impact Reduction

The initial boardwalk design presented a higher potential for ecological disturbance. The original concept included a larger construction footprint, conventional foundation elements, a wider base for stabilization, and a lower structural setting. Overlay analysis between the proposed boardwalk alignment and mapped mangrove vegetation indicated that the initial design could directly affect mangrove habitat and associated root-zone features.

Rather than accepting these impacts as unavoidable, the project team initiated an iterative design review process involving environmental specialists, engineers, designers, and project stakeholders. The central design priority was to avoid mature and reproductively active trees wherever practicable while maintaining the functional requirements of the boardwalk.

The revised design adopted an elevated pile-supported boardwalk. This reduced the construction footprint, minimized excavation requirements, and helped preserve tidal connectivity through the mangrove habitat. Individual pile locations were also micro-sited using GPS-referenced ecological data to avoid mature trees, sensitive root structures, and dense pneumatophore zones where practicable.

This process allowed the design to respond to actual field conditions rather than relying only on the original engineering layout. The estimated reduction in mangrove impact resulting from the design optimization is summarized in Table 1.

Figure 2. Overlay of the initial and modified boardwalk alignments on the mangrove stand. Blue line = modified design; black line = previous design.

Table 1. Estimated mangrove impact reduction through design optimization

Impact Metric	Initial Design	Final Modified Design	Change
Estimated affected mangrove individuals	110	37	−73 individuals
Approx. relative reduction in direct vegetation impact	—	—	~66%

The strongest environmental outcome was achieved through avoidance and minimization before construction, rather than relying primarily on compensation after impact.

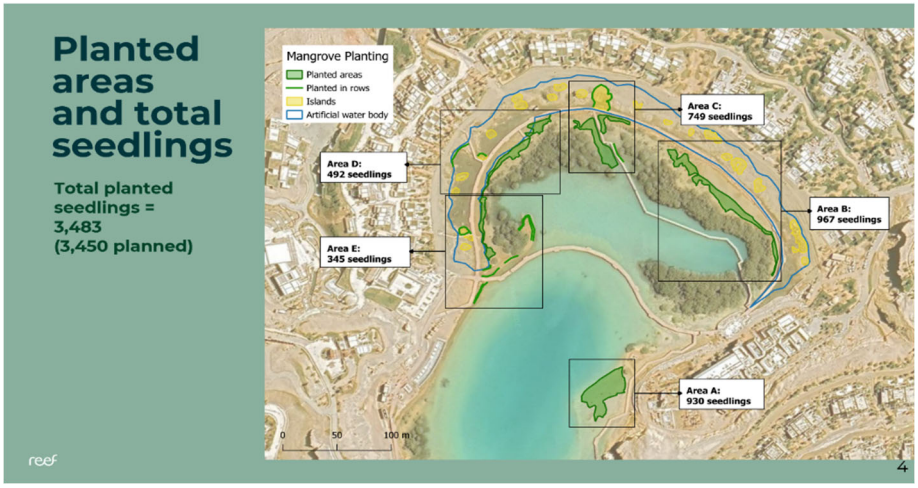
5. Enhancement and Construction-Phase Safeguards

Although design optimization substantially reduced predicted impacts, some residual effects remained. Therefore, habitat enhancement planning was also developed to support long-term ecological resilience. Site-selection and enhancement planning identified suitable areas for approximately 3,450 mangrove seedlings, with 3,483 seedlings ultimately recorded as planted in the enhancement implementation data. Suitability considerations included substrate condition, tidal water circulation, accessibility, proximity to existing mangroves, and salinity conditions. This enhancement component should be understood as a long-term ecological improvement pathway rather than an immediate replacement for established mangrove habitat.

Construction-phase safeguards were implemented through project-specific environmental management requirements. These translated environmental commitments, permit conditions, and mitigation measures into contractor-level controls, including inspections, training, monitoring, reporting, incident response, and corrective-action procedures.

Monitoring activities included ecological observations, water quality monitoring, sediment and siltation controls, routine inspections, and workforce awareness measures. These controls provided a mechanism to verify that design-stage safeguards were supported during construction implementation.

Figure 3. Selected enhancement zones



6. Lessons for Impact Assessment Practice

Several lessons from this case study are transferable to other coastal infrastructure projects:

- Early environmental engagement creates options: arriving before design closure, ecological information lets teams reshape alignments and methods to avoid sensitive receptors; introduced later, the same data becomes a constraint.
- Evidence-based decision-making improves credibility: field surveys, spatial mapping, and quantified impact comparisons give engineers, contractors, and regulators a shared evidence base, making design changes easier to justify.
- The mitigation hierarchy works best when avoidance and minimization come early: enhancement and restoration still matter, but the greatest benefit here came from reducing predicted impacts before construction.
- Environmental compliance can act as a project enabler, not just a set of restrictions: here it translated ecological data into practical controls and a lower-impact design through collaboration with the design team.

7. Conclusion

At the AMAALA Six Senses Resort boardwalk, ecological surveys, spatial mapping, and collaborative design refinement — applied as design inputs rather than post-design checks — reduced estimated mangrove impacts from 110 individuals to 37, an approximate 66% reduction in predicted direct vegetation impact. The case equally shows that design-stage safeguards must carry into construction: contractor controls, monitoring, inspections, and corrective actions were all required to deliver the commitments set during design.

As coastal development expands into sensitive habitats, integrating ecological information into engineering design will only grow more important. Applied early, environmental compliance can act less as a regulatory checkpoint than as a design partner — supporting both project delivery and protection of the ecosystems at stake.

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