# Transforming Conventional Seawalls into Marine Habitats: Eco-Engineered Coastal Structures for Philippine Urban Waterfronts

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***Abstract*— Philippine cities require dependable coastal protection, yet conventional smooth seawalls simplify intertidal habitat and can intensify ecological losses associated with marine urbanization. This integrative literature review examines how eco-engineering can retrofit or redesign vertical coastal structures to retain their safety function while providing habitat. Thirty-one peer-reviewed and institutional sources were synthesized across four themes: ecological effects of shoreline armoring, performance of habitat-complexity interventions, structural and maintenance requirements, and transferability to Philippine urban waterfronts. Evidence consistently favors small-scale additions of pits, crevices, ledges, textured panels, shaded cavities, and water-retaining pools; responses nevertheless vary with tidal elevation, wave exposure, material, pollution, propagule supply, and maintenance. A context-sensitive design is proposed in which the reinforced-concrete wall remains the primary load-bearing system and replaceable habitat panels are zoned vertically, fixed through inspectable corrosion-resistant connections, combined with lower-intertidal water-retaining units, and separated from structurally independent toe protection. Manila Bay is used as the principal application context because flood exposure, subsidence, dense infrastructure, degraded water quality, and large planned coastal investments make ecological co-benefits both valuable and difficult. The review concludes that eco-engineered seawalls are not substitutes for mangroves, tidal flats, setback, or pollution control. They are a pragmatic harm-reduction and habitat-support strategy where hard protection is justified and space is constrained. Philippine pilots should use reference sites, before–after-control–impact monitoring, native-species safeguards, life-cycle maintenance plans, and explicit structural acceptance criteria.**

***Keywords—Biodiversity, Coastal Infrastructure, Eco-Engineering, Living Seawalls, Manila Bay, Nature-Inclusive Design, Philippines, Urban Waterfronts.***

## I. INTRODUCTION

Coastal urbanization replaces heterogeneous shores with ports, reclamation edges, revetments, breakwaters, and vertical seawalls. These structures protect people and assets, but their smooth, steep surfaces usually provide fewer refuges, retain less water at low tide, and support assemblages different from natural rocky shores [1]–[5]. The resulting "ocean sprawl" fragments habitat while increasing the area occupied by artificial substrate [2], [3]. In an archipelagic country, this is not a marginal design issue: Philippine settlements, transport corridors, fisheries, and public spaces are strongly concentrated along coasts.

Metro Manila illustrates the pressure. Manila Bay combines storm-surge and tidal-flood exposure with rapid subsidence, sea-level rise, dense waterfront development, pollution, and major infrastructure proposals [6]–[9]. Conventional defenses may remain necessary at selected urban locations, but a binary choice between a grey wall and unconstrained nature is misleading. Eco-engineering modifies the geometry, material, or operation of built structures to improve ecological performance without relinquishing the engineering service [10]–[13]. Examples include textured tiles, cavities, ledges, drilled pits, flowerpot-like pools, and precast panels that imitate the topographic complexity and water retention of rocky habitat.

This article asks: (1) which eco-engineering features have the strongest evidence on seawalls; (2) how should those features be integrated without compromising structural safety, inspection, drainage, or durability; and (3) what implementation model is appropriate for Philippine urban waterfronts? The objective is not to present a construction-ready detail. It is to translate international evidence into a technically bounded conceptual design and research agenda for Philippine pilots.

## II. METHODS

An integrative literature review was undertaken because the topic spans ecology, coastal engineering, climate adaptation, and urban governance. Searches completed in August 2026 combined "eco-engineered seawall," "living seawall," "habitat panel," "intertidal complexity," "water-

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retaining feature," "marine urbanization," "Manila Bay," "Philippines," "subsidence," and "coastal flood." Peer-reviewed experimental studies and syntheses were prioritized, supplemented by authoritative Philippine and international planning or assessment documents. Sources were included when they reported ecological responses to artificial-shore interventions, defined engineering or monitoring requirements, or established Philippine coastal context. Thirty-one sources were retained.

Evidence was coded by intervention, ecological mechanism, response variable, environmental moderator, and engineering constraint. Because studies differed in climate, duration, taxa, panel form, and sampling design, findings were synthesized narratively rather than pooled statistically. The proposed section drawing was derived from recurring design principles, not copied from a proprietary product. It separates primary structural functions from ecological attachments and identifies site-specific checks that must precede construction.

TABLE I. EVIDENCE SYNTHESIS FOR ECO-ENGINEERED SEAWALL FEATURES

| Feature | Ecological mechanism | Evidence pattern | Design caution |
|---|---|---|---|
| Surface texture and micro-pits | Increase attachment area; create moisture and thermal microclimates | Often increases richness or abundance relative to smooth concrete [12]–[16] | Benefits depend on scale, elevation, orientation, and fouling |
| Crevices, overhangs, and shaded cavities | Provide refuge from heat, desiccation, waves, and predation | Supports mobile fauna and shade-sensitive organisms [12], [15], [17] | Avoid inaccessible debris traps and inspection blind spots |
| Water-retaining pools or pots | Maintain immersion and moderate low-tide stress | Strong tropical evidence, with effects beyond added area alone [14], [18] | Provide overflow, drainage control, safe depth, and cleanability |
| Ledges and shelves | Increase horizontal habitat and sediment retention | Can alter colonization and community composition [11], [13] | Check wave uplift, public safety, and falling-object risk |
| Material and surface chemistry | Influence pH, roughness, porosity, and recruitment | Ecological concrete can improve biological integration [19], [20] | Structural durability and leachate testing remain mandatory |
| Vertical zonation of modules | Matches features to exposure and immersion regimes | Responses vary with tidal elevation and spatial scale [15], [17] | Use local tidal datums, wave climate, and target assemblages |

## III. III. RESULTS

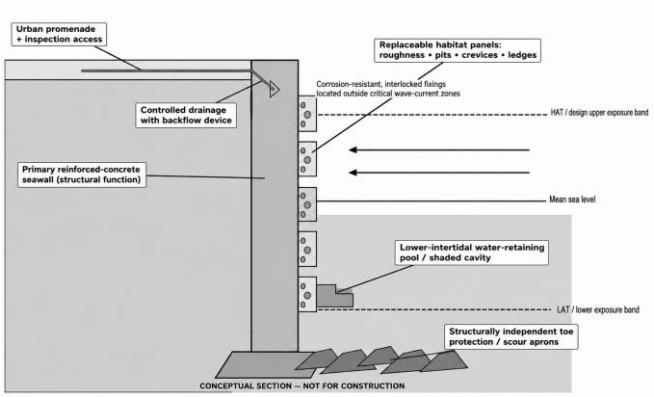
### A. Why Conventional Seawalls Underperform Ecologically

Natural intertidal shores contain cracks, pools, slopes, undersides, variable grain sizes, and surfaces with different solar and wave exposure. Vertical cast concrete compresses that environmental range into a narrow, relatively uniform plane. At low tide it drains quickly and heats; at high tide it offers limited refuge from waves and predators. Artificial structures consequently favor a subset of tolerant or opportunistic species, and may facilitate non-native species, while failing to reproduce the functions of mangroves, seagrass, coral reefs, tidal flats, or natural rocky shores [1]–[5], [21].

Complexity is therefore the central, but not sufficient, design variable. Experiments show that adding pits, grooves, crevices, ledges, or panels can increase local richness and abundance [11]–[18]. Water-retaining features are especially relevant in the tropics because they buffer desiccation and heat during emersion. Loke and colleagues showed that water retention produced biodiversity effects independent of simply increasing surface area [14]. Yet ecological outcomes are heterogeneous. A feature beneficial low on the shore may overheat or collect contaminated sediment higher up; a panel successful in sheltered water may detach or scour under typhoon waves; and added complexity can be colonized by introduced organisms as readily as native ones. Eco-engineering must therefore be hypothesis-driven and locally tested.

### B. A Structurally Bounded Technology Design

Fig. 1 proposes a retrofit logic for an urban seawall. The existing or new reinforced-concrete wall remains responsible for earth retention, global stability, overtopping resistance, and durability. Habitat modules are secondary, replaceable components rather than load-bearing substitutes. Embedded sockets or predesigned rails are preferable to uncontrolled post-installed drilling, which can cut reinforcement, reduce concrete cover, or accelerate chloride-induced corrosion. Fixings require marine-grade material selection, galvanic isolation where dissimilar metals meet, tamper resistance, visual access, and a replacement method that does not damage the wall.




*Note—Conceptual design only. Dimensions, loads, reinforcement, anchors, materials, elevations, drainage, overtopping, scour, geotechnical stability, constructability, accessibility, and maintenance must be verified for each site by licensed Philippine professionals. Ecological targets require baseline surveys and local permitting.*

Fig. 1. Conceptual Cross-Section Of An Eco-Engineered Urban Seawall

Modules are vertically zoned. Upper-intertidal panels emphasize narrow shaded crevices and thermal heterogeneity; mid-intertidal panels combine roughness, pits, and ledges; lower-intertidal units include deeper cavities and water-retaining pools. The drawing also separates toe protection from the attached panels. Armor units or a scour apron must be sized for hydraulics and foundation conditions, while their voids and surface heterogeneity can be ecologically optimized. Controlled promenade drainage and a backflow device reduce direct pollutant pulses and tidal intrusion; they do not replace catchment-scale wastewater and solid-waste management.

This architecture supports adaptive management. Standardized panel footprints can host alternative textures or cavity geometries while preserving the mounting interface.

Damaged panels can be isolated and replaced. Replicated treatments, smooth-wall controls, and nearby natural references allow defensible evaluation. The design also preserves inspection lines around joints, drains, cracks, and the wall toe. These are essential distinctions: a habitat attachment that conceals structural deterioration or creates unacceptable wave loading is not successful eco-engineering.

TABLE II. DESIGN REQUIREMENTS FOR A PHILIPPINE PILOT

| Subsystem | Minimum requirement | Verification | Failure to avoid |
|---|---|---|---|
| Primary wall | Maintain sliding, overturning, bearing, global stability, durability, and overtopping performance | Site-specific structural, geotechnical, hydraulic, and seismic design | Treating habitat panels as structural repair |
| Panel and fixing | Replaceable module; positive mechanical restraint; inspectable, corrosion-compatible connection | Wave and debris load tests; pull-out/fatigue tests; installation QA | Drilling through reinforcement; galvanic corrosion; loose panels |
| Habitat geometry | Replicated roughness, pits, crevices, ledges, shade, and water retention across tidal zones | Prototype colonization and thermal/water-retention trials | One universal geometry deployed at all elevations |
| Toe and scour | Independent sizing for waves, currents, seabed, settlement, and undermining | Hydrodynamic and geotechnical assessment; post-storm bathymetry | Using ecological units as unverified scour protection |
| Operations | Safe access, debris removal, drainage inspection, module replacement, and post-typhoon checks | Asset register and funded maintenance plan | Complexity becoming litter trap or inspection obstruction |
| Ecological safeguards | Native reference targets; invasive-species surveillance; water-quality baseline | BACI monitoring for at least seasonal and multi-year change | Reporting attachment cover alone as ecosystem recovery |

### C. Expected Outcomes and Limits

The most defensible expected outcome is improved habitat quality relative to an otherwise smooth seawall, not restoration of the displaced ecosystem. More surface types should increase niche availability; pools should extend immersion; shaded cavities should reduce thermal stress; and modular replication should create stepping-stone habitat along a hardened shoreline. Experiments and multi-site syntheses report positive responses, but the magnitude and beneficiary taxa vary [11]–[18], [22], [23]. Monitoring should therefore measure species richness, abundance, assemblage composition, native/non-native status, survival in pools, recruitment, temperature, water retention, sediment and litter accumulation, and panel integrity—not merely percent biological cover.

Benefits may extend beyond biodiversity. Visible panels can improve public interpretation of the intertidal zone; standardized modules can support citizen science; and ecological criteria introduced at procurement stage can shift routine maintenance toward nature-inclusive practice. Conversely, poorly designed features may trap waste, harbor mosquitoes where isolated from seawater, create sharp or slippery public interfaces, obstruct inspection, or encourage non-native species. Polluted water can overwhelm habitat gains. These risks are especially material in Manila Bay, where rehabilitation, wastewater control, solid-waste management, reclamation debates, and flood defense interact [6]–[9].

## IV. DISCUSSION

### A. Where the Approach Fits in the Philippines

Eco-engineered seawalls are most appropriate where a hard edge is already present or demonstrably required: ferry terminals, port-adjacent public waterfronts, constrained urban promenades, flood-defense upgrades, and retaining structures with little room for landward setback. They should not be used to justify avoidable reclamation or replacement of mangroves and tidal flats. The preferred adaptation hierarchy is to avoid new hardening, protect existing natural defenses, restore feasible habitats, use hybrid measures, and then improve the ecological performance of unavoidable grey infrastructure [24]–[28], [31].

A Manila Bay pilot should begin at a hydraulically representative but manageable site outside the most contaminated or operationally hazardous zones and should align with national rehabilitation and climate-action commitments [29], [30]. A second city—such as Iloilo, Cebu, or Davao—could later test transferability across tidal range, exposure, water quality, and biogeographic setting. Site selection requires early coordination among local governments, engineering offices, port or reclamation authorities, DENR units, coastal ecologists, fisher and community groups, accessibility specialists, and asset maintainers. Community participation is valuable for site knowledge and monitoring, but cannot replace professional responsibility for structural safety.

### B. Evaluation and Governance

A before–after-control–impact design is the minimum credible evaluation. Baseline surveys should cover the proposed wall, a comparable unmodified wall, and—where available—a natural reference. Replicated panel treatments should be randomized within tidal bands. Monitoring should occur before installation, during early recruitment, across wet and dry seasons, and after major storms. Ecological data must be paired with engineering observations: cracks, anchor movement, abrasion, corrosion, settlement, overtopping damage, debris loads, and maintenance hours. Success criteria should be agreed before installation, including stop or redesign triggers.

Procurement is a decisive but overlooked stage. Performance specifications should define structural boundaries, allowable panel mass and projection, design life, replaceability, inspection clearance, material documentation, and ecological hypotheses. A digital asset register should record module type, elevation, installation date, inspections, repairs, and biological surveys. Open ecological results can accelerate learning, while exact vulnerabilities of critical infrastructure may require controlled access. Long-term ownership and maintenance funding must be assigned before a pilot is celebrated.

Material selection requires a whole-life perspective. Concrete mixes can be adjusted to create texture, porosity, or lower surface alkalinity, but ecological claims must not displace requirements for strength, chloride resistance, abrasion resistance, dimensional stability, and quality control.

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The environmental burden of added modules should be reported through material quantities, expected service life, replacement frequency, and end-of-life route. Locally cast modules may reduce transport and create training opportunities, yet local production is beneficial only if molds, curing, reinforcement cover, and acceptance testing are controlled. Standardization of the attachment interface, while allowing several ecological face designs, offers a reasonable balance between maintainability and experimental learning.

Hydraulic performance deserves equal attention. Projections alter near-wall turbulence and may receive impulsive wave, debris, and uplift loads. At exposed sites, large habitat elements can be inappropriate even when biologically attractive. Physical or numerical modeling should test extreme and service conditions, including oblique waves, overtopping, trapped air, floating debris, and interaction with the toe. Designers should also check whether pools retain water as intended after construction tolerances, settlement, biofouling, and sedimentation. Ecological performance under ordinary tides and structural performance under rare extremes are different tests; both must pass.

Equity and public use shape whether a waterfront intervention is legitimate. Flood protection investments can alter access to fishing grounds, landing points, views, shade, and mobility. Habitat panels below the public edge should therefore be co-designed with safe access routes, universal accessibility, warning and rescue provisions, and designated locations for customary activities. Public interpretation should describe the intervention honestly as habitat enhancement on infrastructure, not as replacement of the original shoreline. Where monitoring uses community volunteers, agencies should provide protocols, safety equipment, data stewardship, and feedback showing how observations affected maintenance or design decisions.

TABLE III. PHASED RESEARCH-TO-IMPLEMENTATION ROADMAP

| Phase | Key actions | Decision gate | Indicative indicators |
|---|---|---|---|
| 1. Baseline and site screening | Map habitat, tidal elevation, waves, scour, drainage, access, water quality, and users | Is hard protection justified and is the site suitable for a safe experiment? | Native/non-native assemblages; temperature; pollutants; defects; maintenance burden |
| 2. Co-design and testing | Develop modular variants; structural calculations; laboratory load, durability, and water-retention tests | Do all variants meet engineering acceptance criteria? | Panel/anchor capacity; abrasion; thermal refuge; retained-water duration |
| 3. Controlled pilot | Install replicated treatments, smooth-wall controls, and monitoring markers | Are there unacceptable safety, maintenance, or invasive-species effects? | BACI ecological response; attachment integrity; debris; public incidents |
| 4. Post-storm review | Inspect after typhoons, extreme tides, debris impacts, and settlement | Repair, redesign, pause, or continue? | Damage state; anchor movement; scour; replacement time and cost |
| 5. Scale and standardize | Publish results; refine specifications; train asset teams; expand only to comparable settings | Is performance reproducible and affordable across the asset life cycle? | Multi-year persistence; cost per metre; inspection time; portfolio-level biodiversity gain |

### C. *Research Gaps*

Philippine evidence is presently the principal gap. Tropical studies from Singapore are highly relevant but cannot substitute for local tests under Philippine typhoon debris, wave exposure, pollution, subsidence, seismicity, maintenance capacity, and species pools. Research should compare locally manufacturable low-carbon mixes, panel orientation, color and thermal performance, pool drainage, larval recruitment, and invasive-species risk. It should also evaluate whether arrays improve connectivity at waterfront scale rather than only increasing organisms on individual panels. Social research is needed on fisher access, public safety, perceived value, vandalism, and willingness of agencies to fund maintenance.

The design claim must remain proportionate to evidence. An eco-engineered wall can be more ecologically functional than a conventional wall, but it is not "nature positive" merely because organisms colonize it. Net outcomes require accounting for the habitat lost, construction emissions, altered hydrodynamics, maintenance, non-native species, and the counterfactual of retreat or habitat restoration [23]–[27]. Transparent accounting prevents ecological enhancement from becoming decorative greenwashing.

## V. CONCLUSION

Eco-engineered seawalls offer Philippine cities a practical way to reduce some ecological harm where hard coastal protection is unavoidable. The strongest design principles are increased surface complexity, shaded refuge, water retention, vertical zoning, modular replacement, and rigorous separation between ecological attachments and primary structural functions. For Manila Bay and other urban waterfronts, these features must be coupled with hydrodynamic, geotechnical, structural, seismic, corrosion, drainage, accessibility, and maintenance design. They cannot compensate for polluted water or justify destruction of mangroves and tidal flats.

The recommended next step is a controlled, independently evaluated pilot rather than immediate large-scale rollout. A credible programme would use local baseline data, replicated panel variants, smooth-wall controls, natural references, BACI monitoring, post-typhoon inspection, invasive-species safeguards, and life-cycle ownership. With those conditions, conventional seawalls can become more than inert barriers: they can remain reliable public infrastructure while functioning as modest, measurable habitat nodes within a wider strategy of coastal risk reduction and ecosystem recovery.

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