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Neglected supralittoral habitats on coastal artificial structures

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Artificial structures are ubiquitous features of urbanized coastal landscapes, but research and management solutions have focused on lower shore communities, neglecting the terrestrial-marine transitional zone. The ecological role of supralittoral habitats on artificial structures generates unique opportunities for the conservation of native species and reducing the spread of nondesired species.

Urban sprawl and the addition of artificial habitats

Coastal artificial structures (see Glossary), such as breakwaters, groynes, and seawalls, are proliferating along global coasts to support trade, urban living, tourism, industrial production, and, increasingly, as a defense of infrastructure from extreme weather events and sea-level rise [1–3]. **Urban sprawl** has generated interest in the ecology of coastal artificial structures and, more recently, engineering solutions for either reducing their impacts or enhancing their ecological value [i.e., **integrated greening of gray infrastructure (IGGI)**] [1,3].

Substantial research has compared benthic communities on artificial structures with those on natural rocky shores and attempted to identify physical features (e.g., construction material, topography, inclination) that regulate species diversity and **ecosystem functioning**. Most of this research has focused on low-shore and subtidal habitats and hence on fully marine species, with less attention to the **supralittoral zone**.

Coastal artificial structures are often built onshore and extend vertically beyond the supratidal zone into fully terrestrial environments [1], creating habitat for species more loosely dependent on the marine environment or with strong terrestrial links. A limited understanding of natural and human factors structuring these **transitional habitats** and their ecological connections with adjacent subtidal and terrestrial habitats, together with their neglect in management plans, has resulted in missed conservation opportunities.

Ecological communities in the supralittoral zone

Coastal artificial structures support diverse plant assemblages, generally composed of ruderal species [4]. For example, 17 and 13 plant species were recorded on breakwaters and groynes along the coasts of Chile and Italy, respectively [4]. Proximity of artificial structures to shipping terminals, roadsides, and public and house gardens facilitates their colonization by non-native plants [4].

Diverse assemblages of native and non-native animals also use artificial structures [4–7] (Figure 1). Structures made of rock boulders with cryptic spaces that can be used as hideouts often attract **synanthropic**, feral, and pest species such as rats, pigeons, gulls, cats, and dogs [4–6], as well as non-native predators that use intertidal habitats as feeding grounds [8].

On the other hand, there are examples of supralittoral habitats on artificial structures being used by native species, including birds, mammals, and reptiles (Figure 1B), some with high conservation value, such as those listed as Near Threatened (e.g., the Inca tern, *Larosterna inca*), Vulnerable (e.g., the Humboldt penguin, *Spheniscus humboldti*, and the Eurasian oystercatcher, *Haematopus ostralegus*), or Endangered (e.g., the sea otter, *Lontra felina*) by the International Union for Conservation of Nature (IUCN) (Table 1). Thus, artificial structures offer opportunities to protect multiple vulnerable/endangered species through the provision of permanent, transitory, or 'stopover' habitat (Figure 1B).

Land–sea connectivity and anthropogenic threats

The **connectivity** between terrestrial and marine ecosystems is a key determinant

Glossary

Coastal artificial structures: hard infrastructure, such as breakwaters, groynes, jetties, seawalls, floating pontoons, piers, and bridge and mooring pilings, introduced onshore or into coastal waters for urban development and to support maritime, industrial, recreational, and tourist activities.
Connectivity: the degree to which populations or communities occupying distinct and geographically separated patches of habitat are connected through the movement of either adult or juvenile stages.
(Ecological) Subsidy: flows of energy, nutrients, organic matter, and living organisms between ecosystems.
Ecosystem functioning: biological, geochemical, and physical processes that regulate flow of energy and materials through the biotic and abiotic components of an ecosystem.
Integrated greening of gray infrastructure (IGGI): conservation strategy for enhancing the biodiversity of hard infrastructure that cannot be replaced with green or blue solutions through the inclusion of ecological principles in their design.
Supralittoral zone: the height of a shore that is above the high-tide mark and is reached by seawater only during storms at high tide. It represents the transitional habitat between the terrestrial and marine systems (see Transitional habitat).
Synanthropic species: undomesticated species living in close association to humans that benefit from the alteration of environmental conditions, resource availability, and species interactions generated by human activities.
Transitional habitat: zone supporting communities composed of species that are adapted to diverse and variable environmental conditions such as those characterizing the boundary between terrestrial and marine ecosystems.
Urban sprawl: rapid and uncontrolled expansion of cities and towns, often associated with low density residential housing built on undeveloped land adjacent to a city.

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Figure 1. Coastal artificial structures biodiversity and management. (A) Unmanaged coastal artificial structure, where human activities, such as littering and light and noise pollution, enhance synanthropic, non-native, or pest species, the potential of pathogen transmission, and consumption impacts on local biota, eroding the ecological and societal value of the structure. (B) Ecologically improved rock revetments (e.g., breakwater), supporting diverse animal and plant communities, including species of high conservation value, and ecological interactions at the marine–terrestrial interfaces, enhancing people's recreational activities and well-being. Examples of improvements include the addition of artificial bird nests (e.g., for terns), slopes and large rock boulders for pinnipeds, filling gaps among boulders with soil to reduce habitat for pests and to enhance plant establishment, and the placement of information panels. Positive effects of sound management of the supralittoral zone propagate to intertidal and subtidal habitats. Illustration by Jorge Varela.

of their structure and functioning. On natural rocky coasts, marine inputs (e.g., algal wrack, fish remains, seabird guano, and carcasses) support high plant and arthropod abundances in the supralittoral zone, fueling inland food webs [12]. Likewise, fertilization by bird guano, leaching down from upper shore deposits, can boost marine productivity.

The connectivity between terrestrial and marine communities supported by marine artificial structures is not well understood [13]. In comparison with natural shores, the **subsidy** of macroalgal wrack or carcasses of marine species to supralittoral habitats is expected to be drastically reduced on vertical and smooth structures. The composition of upper shore assemblages, and hence their value as conservation habitats, is influenced by artificial structures, which facilitates movements of feral or pest species across the marine–terrestrial boundary (Figure 1A). Some of these species (e.g., rats) prey at lower shore levels [14], potentially jeopardizing the benefits of engineering solutions implemented to sustain marine biodiversity. Others (e.g., cats) can have strong negative effects on populations of terrestrial species or nesting seabirds in the surroundings of artificial structures. In addition, feral animals thriving on artificial structures can represent an important reservoir of parasites and diseases that can be transmitted to humans.

The presence of people, littering, and light and noise pollution can alter land–sea connectivity and further limit the value of artificial structures for sensitive species, especially in urban contexts (Figure 1A). Food scraps, fish discards, and unused bait produced by recreational activities can subsidize the populations of synanthropic species. Likewise, disturbance due to maintenance works can completely disrupt artificial habitats, promoting ruderal and non-native species dominance [3].

Opportunities for biodiversity conservation and human well-being

Most solutions to sustain marine biodiversity through IGGI deal with the enhancement of physical features of artificial habitats at mid- and low-shore heights. However, pursuing conservational targets with an exclusive focus on intertidal habitats could inadvertently impact the ecology and connectivity of supralittoral communities. Thus, restoring the natural flow of organisms, materials, and energy

Table 1. Examples of species included in IUCN Red List that have established permanent populations on coastal artificial structures

Group	Species	Country	Artificial structure	IUCN Red List status[a]	Refs
Plant	Broad-leaf plantain – *Plantago major*	Chile/Italy	Breakwater	LC	[4]
Plant	Sea fennel – *Crithmum maritimum*	Italy	Breakwater	LC	[4]
Reptile	Atacamen Pacific iguana – *Microlophus atacamensis*	Chile	Breakwater	LC	[4]
Reptile	Four-banded Pacific iguana – *Microlophus quadrivittatus*	Chile	Breakwater	LC	[4]
Bird	Humboldt Penguin – *Spheniscus humboldti*	Chile	Breakwater	VU	[5]
Bird	Kelp gull – *Larus dominicanus*	Chile	Breakwater	LC	[5]
Bird	Inca tern – *Larosterna inca*	Chile	Seawall	NT	M. Thiel, personal observation
Bird	Little penguin – *Eudyptula minor*	New Zealand Australia	Breakwater	LC	[6,7]
Bird	Black-faced cormorant – *Phalacrocorax fuscescens*	Australia	Breakwater	LC	[9]
Bird	Eurasian oystercatcher – *Haematopus ostralegus*	UK	Breakwater	VU	Waterbird counts at Rhos Point 2013–2023[b]
Bird	Dunlin – *Calidris alpina*	UK	Breakwater	LC	Waterbird counts at Rhos Point 2013–2023[b]
Mammal	Sea otter – *Lontra felina*	Chile/Peru	Breakwater	EN	[10]
Mammal	California sea lion – *Zalophus californianus*	USA	Breakwater	LC	[11]

[a]Checked at https://www.iucnredlist.org/ on the 19 January 2025.
[b]https://www.conwy.gov.uk/cy/Resident/atoztest.aspx?AZListing_AtoZLetter=W.

across supralittoral habitats on artificial structures is key for sustaining their functioning but also for the conservation of adjacent marine and terrestrial ecosystems [13].

Targeted addition or management of supralittoral habitat features can favor species of high conservation value over those that are undesired (Figure 1B). For example, adding sloped ramps, large boulders, and/or haulout platforms could facilitate access and use of artificial supralittoral habitats by pinnipeds (Figure 1B). Management targets, and hence solutions to achieve them, are not universal, but depend on local ecological and socioeconomic contexts. For example, drilling holes in vertical surfaces could attract some bird species, whereas adding artificial nests could be necessary for others. Filling gaps among boulders with soil would reduce habitat space for pest species (e.g., rats) while enhancing plant settlement. Seeding with native plants could favor the establishment of supralittoral vegetation able to deliver multiple services, including algal wrack trapping, habitat provision to animals, reduced colonization by exotic species, and drainwater filtration (Figure 1B). The development of vegetation is not, however, always desirable: For example, terns require open surfaces covered with sand and shell hash for nesting.

The presence of highly diverse communities or emblematic species would add to the cultural, educational, and spiritual dimension of artificial habitats, with positive effects on human lifestyle and health [15]. Artificial structure sections not used for commercial operations could be habilitated for carefully organized public access, with some sections set aside exclusively for sensitive species. Adding educational resources (e.g., observation platforms and information panels) could further enhance the recreational and conservation value of supralittoral habitats (Figure 1B).

In conclusion, given the projected increase in the use of coastal artificial structures [2], considering the biology and ecology of species using supralittoral habitats will improve IGGI. Finally, it is worth stressing that IGGI can mitigate the impacts of coastal artificial structures but cannot fully offset them.

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Declaration of interests

No conflicts of interest are declared.

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