

Annotated Bibliography on  
**Innovations in Cost-effective and Environmentally Sustainable Coastal  
Protection Structures**



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## **Introduction:**

Protecting the coastline from wave attack and erosion during high tides and severe storms. Protecting the coastline from flooding by seawater, especially during storms and high tides. Conserving fragile coastal ecosystems including saltmarshes, mudflats, sand and shingle spits and sand dunes. Furthermore, nature-based interventions provide a wide range of benefits for other sectors such as tourism and fisheries as well as coastal protection. Living shoreline solutions moderate the impact of waves and storm surges while providing self-sustaining protection. Hard coastal infrastructure can be cost-effectively adapted to sustain greater biodiversity. This annotated bibliography contains articles' abstracts from 2022-2023.

This benefits ELSRC / Coastal Management (CM) program researchers.

E-resources used: Scopus

**Contact NSTIC to request full-text articles.**

## **Articles' Abstracts:**

1. Sedighi M, Pourmoghaddam Qhazvini P, Amidpour M. (2023) Algae-Powered Buildings: A Review of an Innovative, Sustainable Approach in the Built Environment. *Sustainability*; 15(4):3729.

**Abstract:** Environmental pollution, global warming, energy consumption, and limited natural resources are some key factors from which today's built environment faces interrelated problems and their management plays a vital role in sustainability. The building sector is involved in 35% of global energy usage and 40% of energy related CO<sub>2</sub> emissions. Application of bioactive elements on buildings' façades is a novel approach for solving the above-mentioned problems. Management of some important factors such as thermal comfort, energy efficiency, wastewater treatment, and CO<sub>2</sub> capture is positively affected by bioactive façades because of their environmentally friendly nature. They also have positive effects on global warming, pollution control, social wealth, and sustainable development on a larger scale. The buildings integrated with photobioreactors (PBRs) can meet their thermal needs due to thermal insulation, shading, solar collection, and light-to-biomass conversion. Energy savings up to 30% are estimated to be met by PBR-integrated buildings due to reduced heating, cooling, ventilation, and lighting loads. The above amount of energy saving results in less CO<sub>2</sub> emission. Moreover, the algae-integrated buildings can sequester CO<sub>2</sub> with an average sequestration rate of 5 g/ft<sup>2</sup>/day when optimum growing environments and operation modes are implemented. This study is an overview of microalgae intervention and PBR-adapted buildings as an innovative approach for energy efficiency in the built environment with regard to implemented or speculative cases, pros and cons, challenges, and prospects.

2. Salauddin, M., Shaffrey, D., Habib, M.A. (2023) .Data-driven approaches in predicting scour depths at a vertical seawall on a permeable shingle foreshore. *Journal of Coastal Conservation*, 27(3), 18.

**Abstract:** Despite recent research efforts in advancing machine learning (ML) tools to predict nearshore characteristics at sea defences, less attention has been paid to ML algorithms in predicting scouring characteristics at vertical seawalls. In this study, four ML approaches were investigated, including gradient boosting decision trees (GBDT), random forest (RF), support vector regression (SVR), and ridge regression (RR). These approaches were utilised to predict scour depths at the toe of an impermeable vertical seawall in front of a permeable shingle slope. The developed ML algorithms were trained and tested (70% for training and 30% for testing)

using the scouring datasets collected from laboratory tests performed on seawalls in a 2D wave flume at the University of Warwick. A novel hyperparameter tuning analysis was performed for each ML model to tailor the underlying dataset features while mitigating associated data overfitting risks. Additionally, the model training process demonstrated permutation feature importance analysis to reduce overfitting and data redundancy. The model predictions were compared with the observed values using the coefficient of determination ( $R^2$ ) score, root mean square error (RMSE), and Pearson correlation R-value. Consequently, the RF and GBDT methods accurately predicted scour depths at the toe of vertical seawalls with shingle foreshores. This study produced data, information, and a model that could directly or indirectly benefit coastal managers, engineers, and local policymakers. These benefits included forecasting scour depths and assessing the impact on the structural integrity of the sea defences in response to the threat imposed by extreme events, which are essential for the sustainable management of coastal protections and properties behind such structures in coastal areas.

3. Perricone, V., Mutalipassi, M., Mele, A., Buono, M., Vicinanza, D., & Contestabile, P. (2023). Nature-based and bioinspired solutions for coastal protection: an overview among key ecosystems and a promising pathway for new functional and sustainable designs. *ICES Journal of Marine Science*, fsad080.

**Abstract:** Coastal erosion is occurring at a faster rate than in the past. The adverse impacts are not negligible at environmental, economic, and socio-cultural levels. Hence, coastal protection is currently seen as an emerging need to counteract erosion impacts and their many negative effects on worldwide ecosystems. In this regard, natural systems and their organisms represent a complex system of solutions that can efficiently create and/or inspire the development of natural, sustainable, and cutting-edge coastal barriers. Coastal ecosystems, such as coral reefs, oyster reefs, mangroves, saltmarshes, seagrasses, and polychaete reefs, act as a natural barrier for destructive waves and wind forces. Moreover, living organisms have evolved unique strategies to withstand their environmental hydrodynamic loadings. This review intends to provide an overview regarding natural systems and related nature-based and bioinspired strategies in the specific field of coastal protection, describing the state of the art, methods, processes, and tools, as well as delineating a promising pathway for new functional and sustainable designs.

4. Zhang, X., Song, H., Zhuang, H., ...Hong, X., Zhang, Z. Calculating the carrying capacity of bivalve mariculture in the Changshan Archipelago (Bohai Strait, China): Ecopath modeling perspective (2023). *Journal of Sea Research*, 192, 102367.

**Abstract:** Aquaculture has an important role in ensuring human food security and boosting global economic development. Sustainable aquaculture has been confronted with the challenge of balancing economic growth and environmental protection. As an essential part of aquaculture planning, the assessment of carrying capacity based on ecosystem models can be used to significantly guide sustainable management. The Ecopath approach was selected to construct a food web model of the Changshan Archipelago ecosystem, an ecologically important region with long-standing mariculture activities in China. The carrying capacity of bivalve mariculture was also calculated from the model. The results demonstrated that the current bivalve mariculture biomass ( $45.80 \text{ t}\cdot\text{km}^{-2}$ ) is below the production carrying capacity ( $72.65 \text{ t}\cdot\text{km}^{-2}$ ) but it is greatly above the ecological carrying capacity ( $21.06 \text{ t}\cdot\text{km}^{-2}$ ). We also discovered that the ecotrophic efficiency of phytoplankton is close to 1 in the model, which shows that the local primary productivity has been efficiently utilized. Based on ecological network analysis, the values of the energy and cycle index indicate that the Changshan Archipelago is in a mature and stable stage, and a low value of the connectance index indicates a relatively simple ecosystem food web. These findings substantially contribute to our understanding of the Changshan Archipelago ecosystem structure and pave the way for effective management on the coastal archipelago.

5. Foss O., Blenkinsopp C.E., Bayle P.M., Martins K., Schimmels S., Almeida L.P. (2023). Comparison of dynamic cobble berm revetments with differing gravel characteristics. *Coastal Engineering*, 183, art. no. 104312. Elsevier B.V.

**Abstract:** Pressure on the coastline is escalating due to the impacts of climate change, this is leading to a rise in sea-levels and intensifying storminess. Consequently, many regions of the coast are at increased risk of erosion and flooding. Therefore coastal protection schemes will increase in cost and scale. In response there is a growing use of nature-based coastal protection which aim to be sustainable, effective and adaptable. An example of a nature-based solution is a dynamic cobble berm revetment: a berm constructed from cobble and other gravel sediments at the high tide wave runup limit. These structures limit wave excursion protecting the hinterland from inundation, stabilise the upper beach and adapt to changes in water level. Recent experiments and field applications have shown the suitability of these structures for coastal protection, however many of the processes and design considerations are poorly

understood. This study directly compares two prototype scale laboratory experiments which tested dynamic cobble berm revetments constructed with approximately the same geometry but differing gravel characteristics; well-sorted rounded gravel (DynaRev1) and poorly-sorted angular gravel (DynaRev2). In both cases the structures were tested using identical wave forcing including incrementally increasing water level and erosive wave conditions. The results presented in this paper demonstrate that both designs responded to changing water level and wave conditions by approaching a dynamically stable state, where individual gravel is mobilised under wave action but the geometry remains approximately constant. Further, both structures acted to reduce swash excursions compared to a pure sand beach. However, their morphological behaviour in response to wave action varied considerably. Once overtopping of the designed crest occurred, the poorly-sorted revetment developed a peaked crest which grew in elevation as the water level or wave height increased, further limited overtopping. By comparison, the well-sorted revetment was characterised by a larger volume of submerged gravel and a lower elevation flat crest which responded less well to changes in conditions. This occurred due to two processes: (1) for the poorly-sorted case, gravel sorting processes moved small to medium gravel material.

6. Morris, R. L., Fest, B., Stokes, D., Jenkins, C., & Swearer, S. E. (2023). The coastal protection and blue carbon benefits of hybrid mangrove living shorelines. *Journal of environmental management*, 331, 117310.

**Abstract:** Hybrid living shorelines use a combination of engineered structures with natural ecosystems to achieve coastal protection and habitat restoration outcomes, with added co-benefits such as carbon sequestration. Rock fillets constructed along eroding estuarine banks are designed to accumulate sediment, establish mangroves, and stabilise the shoreline. There is, however, a lack of data to support whether rock fillets are achieving these goals. We used a chronosequence of rock fillets to determine their effect on mangrove development, bank stabilisation and carbon sequestration in four estuaries in New South Wales, Australia. Aboveground biomass and adult density increased with age of rock fillets, and mangrove structure was similar to a natural fringing mangrove after 15 years. The rock fillets accumulated sediment, which reduced the eroded estuary bank height, however, little effect of the fillets on bank slope was observed. Sediment carbon stocks were not different between rock fillets, eroding estuary banks and natural fringing mangroves. Rock fillet design had a significant effect on mangrove structure and coastal protection function, with greater wave transmission through lower rock fillets, suggesting design optimisation is needed. As the construction cost

of the rock fillets was equal or less than traditional rock revetments, where suitable they present a more economic and environmentally sustainable solution to estuarine erosion management.

7. Sriganesh. J, Sundar, V., Sannasiraj, S.A., Mural, K., (2023). Coastal Management Information Systems(CMIS) for South Indian Coastal States. Lecture Notes in Civil Engineering, 321 LNCE, pp. 393-411.

**Abstract:** The coasts are exposed to hazards that are natural (global warming-induced sea-level-rise, river mouth closure by siltation, changing climate with the increased frequency of cyclonic storm surge, coastal flooding, tsunami, etc.) and due to anthropogenic activities (shoreline erosion, sewage treatment plants, desalination plants, etc.). There are several coastal protections that are in vogue for a specific (single) hazard around the world and different advanced techniques available to protect and preserve the coasts from such hazards. Apart from combating the hazards, there is rapid progress in coastal development. All of these might have provoked the thought of the necessity of the coastal management information to the scientific and engineering coastal working community. The Coastal Management Information System (CMIS) mainly focuses on the in situ data collection of environmental data for the planning, design of structures and schemes for sustainable coastal conservation and development. The monitoring parameters are wave, current, wind, tide, bathymetry, beach profile, shoreline, sediment characteristics in near-shore as well as offshore in case estuarine coasts the riverine data such as river current, discharge, conductivity, temperature along with the depth in a different location from sea to 2 km were measured. Although three coastal sites with different coastal features, Devaneri in Tamil Nadu, Ponnani in Kerala and Karaikal in Puducherry, were selected for this purpose, salient details only for the site along Karaikal are reported herein.

8. Zhang, X., Biswas, W. K., Watt, A., Philip, L., & Sadler, S. (2023). Techno-Economic and Environmental Analysis of Decommissioned Flowline, Umbilical, and Tubular for Breakwaters. Buildings, 13(1), 225.

**Abstract:** This paper presents the application of recycled tubular, flowline, and umbilical in coastal protection structures. Flowline and tubular are found to improve the load resistance capacity of concrete beams. Embedment of flowline, umbilical, and tubular into concrete beams would be beneficial to the structural performance, which do not noticeably alter the initial cracking strength of the concrete beam but will provide good post-cracking resistance. A techno-economic analysis was performed, which revealed that coastal protection concrete structures with decommissioned components accounting for more than 25% of the concrete



weight could be both economically viable and environmentally friendly options. Since global warming is the most dominant environmental impact (i.e., 63%), recycling these decommissioned components from offshore structures could impose positive environmental impacts. Given the limited supply of construction materials in the remote coastal area as well as its proximity to decommissioned oil and gas rig sites, these decommissioned components could have great potential for use as construction materials in the coastal areas adjacent to the oil exploration. This preliminary study finds no showstopper for the concept of recycling the mentioned decommissioned components as coastal protection concrete structures from structural performance, environmental impact, and economic perspectives.

9. Mavroulis, S., Vassilakis, E., Diakakis, M., Konsolaki, A., Kaviris, G., Kotsi, E., ... & Voulgaris, N. (2022). The Use of Innovative Techniques for Management of High-Risk Coastal Areas, Mitigation of Earthquake-Triggered Landslide Risk and Responsible Coastal Development. *Applied Sciences*, 12(4), 2193.

**Abstract:** Coastal areas constitute a very dynamic environment, balancing between numerous natural and anthropogenic processes liable to sometimes hazardous geomorphic phenomena. Especially in tectonically active coastal regions and areas of high economic value, slope failures can have significant impacts and therefore need careful and detailed examination. This work uses Unmanned Aerial System (UAS)-aided photogrammetry and Terrestrial Laser Scanning (TLS) in tectonically active segments of the coastal zone of the Ionian Islands in Greece, to explore how their capabilities can help to improve our understanding of the structural integrity of the slopes. Results show that the two approaches are able to extract large numbers of discontinuity facets, in a more practical, rapid and safe way than conventional methods of rock slope stability analysis extending to unreachable yet important parts of the slope. Through this holistic record of the structural condition of the slope the two applications allow the identification of segments that are more prone to instability and failure. In this way, they improve our understanding of the prioritization of interventions aiming to enhance the prevention of slope failures, mitigating the associated risk and improving local development in these high-value locations.

10. Le Xuan, T., Ba, H. T., Thanh, V. Q., Wright, D. P., Tanim, A. H., & Anh, D. T. (2022). Evaluation of coastal protection strategies and proposing multiple lines of defense under climate change in the Mekong Delta for sustainable shoreline protection. *Ocean & Coastal Management*, 228, 106301.

**Abstract:** Coastal protection measures and management play an important role in coping with coastal disasters and climate-induced sea-level rise. In this study, the success and failure of typical coastal protection works of the Vietnamese Mekong Delta (VMD) are reported and documented from field observations over a study period of 10–15 years. The coastal protection structures evaluated include revetments, geotubes, t-shaped bamboo fences, Pile-rock breakwaters, Busadco's breakwaters, Semi-Circular breakwaters, and Hollow triangle breakwaters. This paper briefly reviews the current situation of coastline erosion problem and accretion in the VMD and illustrates the severity of the current erosion rate that threatens the safety of coastal communities. The paper then evaluates the advantages and disadvantages of various coastal management approaches currently in practice in the VMD to classify different types of possible measures for coastal management with the aim to find holistic measures for planning which require low construction investment. Integrated coastal management and planning are outlined at a regional scale followed by the lessons learned from the previous coastal protection works, and finally the multiple lines of defense (MLD) solution is proposed, which is a green infrastructure inspired nature-based solution. The MLD solution can improve biodiversity, facilitate mangrove forest restoration, and ensure sustainable livelihoods for local communities. Integrated coastal planning and management solutions that are based on the MLD principle are expected to withstand coastal disasters under future climate change, and sea-level rise on the VMD.

11. Mustafa Mahmoud Almaghraby, Rawya Monir Kansoh, Moheb Mina Iskander., (2022). Hydrodynamic assessment of artificial shell for costal protection, *Ocean Engineering*, Volume 266, Part, 112743.

**Abstract:** As a novel type of composite breakwater, hollow artificial shells based on rubble mound bases are proposed. The main concept is using shapes from nature to overcome a nature phenomenon (waves). This type of shells is distinguished from other species. Its length and width are almost twice the height, which increases the stability of every individual shell. Additionally, the out-layer grooves and the semicircular shape smoothly dissipate incident waves. The new composite breakwater was investigated physically in a wide wave flume under the effect of regular waves. The breakwater performance was introduced through wave reflection, wave transmission, and wave dissipation coefficients. Several varying wave actions (wave height, wave period) were applied to the breakwater in four states: emergent, partially submerged, submerged and fully submerged. The partially submerged case showed the best efficiency compared with other states. The reflection coefficient ranges from 0.16 to 0.46, the

transmission coefficient ranges from 0.3 to 0.48, and the dissipation coefficient ranges from 0.75 to 0.92. The Partially submerged breakwaters have been compared with some of the most commonly used types of breakwaters, and have shown to have better efficiency, particularly in areas with short coastal waves. Also, the crest width of a submerged breakwater can be reduced dramatically to less than half, by deploying artificial shell blocks on the crest.

12. Blackwood, L., Renaud, F. G., & Gillespie, S. (2022). Nature-based solutions as climate change adaptation measures for rail infrastructure. *Nature-Based Solutions*, 2, 100013.

**Abstract:** The transport sector fulfils crucial economic and social functions with railways being instrumental in the safe, efficient, and reliable movements of people to their destinations and goods to market. One of the most critical vulnerabilities in the railway transport system is the low flexibility of both infrastructure and operations in the event of disturbances including those caused by extreme weather events such as floods, droughts, storm surges and temperature extremes. With the frequency and intensity of such events being projected to increase, the failure to proactively consider the impacts of a changing climate on new and existing infrastructure raises the possibility of increased service disruption and adverse economic impacts as climate change progresses. Nature-based solutions (NbS) present long-lasting, cost-effective and environmentally sustainable climate change adaptation (CCA) options. However, as an effective alternative or complement to grey (engineered) solutions, they are still in their infancy, especially within the railway sector. To date very few studies have investigated the role of NbS for CCA in the railway transport system. Recognizing the importance of the rail industry's need to adapt its infrastructure to accommodate current weather extremes and a changing climate, this review paper examines NbS being used as CCA measures both in the rail context, and in non-rail contexts which may be transferable to the rail sector. Our review demonstrates that there are significant knowledge gaps that may hinder the uptake of NbS in the rail environment which warrant further research to support the inclusion of NbS as viable CCA options for rail infrastructure. Better understanding of these issues is required for the development of rail sector specific guidance and will enable better design, implementation, and dissemination of NbS as credible alternatives or complements, and more sustainable CCA measures.

13. Chen, Wen L. and Muller, Peter and Grabowski, Robert C. and Dodd, Nicholas. (2022) Green Nourishment: An Innovative Nature-Based Solution for Coastal Erosion, *Frontiers in Marine Science*, 8.

**Abstract:** Coastal erosion poses an urgent threat to life and property in low-lying regions. Sand nourishment is increasingly used as a nature-based solution but requires significant natural resources and replenishment over time. In this study, a novel form of nourishment is explored that combines shoreface nourishment and seagrass restoration to mitigate coastal erosion (i.e., green nourishment). Using the coastal morphodynamic model Xbeach, the impact of seagrass planting on wave energy dissipation, sediment erosion and transport, and morphological evolution of a cross-shore profile was studied for mild wave conditions and an intense storm. Model results indicate that a seagrass meadow enhances the wave energy dissipation provided by a shoreface nourishment, and suggests that it may be particularly effective in sediment transport mitigation when implemented in a sheltered nearshore area. The shoreface nourishment reduced the wave height on the seagrass meadow, and reduced the rate of seagrass destruction by deposition or erosion above the grass height after the storm event. Green nourishment also reduced beach foreshore erosion caused by a simulated storm event. An alternative, more cost-effective planting technique using seagrass seeds was explored, which showed similar coastal erosion protection benefits for seagrass transplants. This modeling study found that green nourishment is potentially an effective nature-based solution for coastal erosion and flooding on sandy coasts, and future studies are recommended to evaluate its morphological, ecological and flood risk reduction benefits in the field.

14. Rekha, P. N., & Vijayan, K. K. (2022, August). Water Management for Sustainable Brackishwater Aquaculture in Coastal Ecosystem-Innovative Approaches. In Transforming Coastal Zone for Sustainable Food and Income Security: Proceedings of the International Symposium of ISCAR on Coastal Agriculture, March 16–19, 2021 pp. 433-453. Springer International Publishing.

**Abstract:** Brackishwater aquaculture is a coastal farming activity, which aims at deriving maximum benefits from unproductive and marginally productive coastal lands and brackish water bodies, and it has contributed significantly to the progress of the country's economy as well as the economic well-being of the rural poor. It is a fast-growing food industry, and the success mainly depends on the availability of good and adequate quality source water and water management during culture. Hence, the water management in coastal brackishwater aquaculture is paramount, which starts with the identification of good quality and adequate water resources, water monitoring during culture for maintenance of the optimum water quality, and discharge water management by reducing, reusing recycling, and remediation technologies. Coastal watershed-based integrated water resource management using the

advancement in geospatial modeling, remote sensing, and geographical information system (GIS) helps to identify the potential site, water source, and its salinity regime during different seasons and to minimize the impact of upstream activities on the coastal aquaculture as well as the impact of aquaculture on coastal ecosystem. Of late intensive coastal aquaculture is rapidly expanding with the introduction of *Penaeus vannamei* which uses large water volume and high protein content in feed which results in significant nutrient-rich effluents. Recirculating aquaculture systems (RASs) seem to be a solution. Development and advancement of RAS, raceways, integrated multi tropic aquaculture (IMTA), zero water exchange systems, biofloc, seaweed bioremediation, algal bioreactor-based RAS, and aquaponics offer scope for higher productivity with better water management practices that maintain the serenity of coastal ecosystems. In the present article, all the above-mentioned water management technologies in brackish water aquaculture have been discussed for pristine coastal ecosystems.

15. Vergiev, S. (2023) Comparative study of the native to the Bulgarian Black Sea Coast plant species for erosion and flooding control of coastal areas. Sustainable Development and Innovations in Marine Technologies - Proceedings of the 19th International Congress of the International Maritime Association of the Mediterranean, IMAM 2022, pp. 421–425.

**Abstract:** Sustainable development of coastal areas suggests applying planting and transplanting techniques based on well adapted plants with extensive root systems instead of artificial coastal stabilization and protection structures. In order to compare the capacity of plant species for erosion and flooding control, a multidisciplinary study based on GIS mapping and modelling of seven study sites over the Bulgarian Black Sea Coast, as well as results from flooding simulations was conducted. In addition, three hand-planted polygons were monitored and compared to natural ones. A strong correlation between percentage participation of the native, salt-tolerant plant species in dune vegetation and dynamic of the shoreline was observed. Polygons with prevailing of species from the family Poaceae had a more stable coastline, unlike polygons with predominance of species from the Cyperaceae and Asteraceae families. The investigated species showed high tolerance to sea water immersion and high viability.

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