Guidance to support the use of ecological enhancement features on coastal defence structures and assets

Guidance note

Reference number: GN064

Document owner: Marine and Coastal Ecosystems team (NRW)

What is this document about?

Guidance document to provide information and demonstrable evidence on the benefits and value for money case of using ecological enhancements in coastal structures.

Who is this document for?

Stakeholders that are planning, delivering, and maintaining coastal assets.

Contact for queries and feedback

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Version history

Document version	Date published	Summary of changes
1.0	July 2022	Document published
2.0	August 2026	Restructured chapters: New case studies added showing scaling up of projects; New chapters on communication and engagement and recommendations; New assessment form

Review date: June 2028

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Contents

Acknowledgements

Thanks are extended to Samantha Buck from Artecology, Rory Atton from ARCmarine, Alice Hall from the University of Plymouth and Ruth Callaway from Littorina for helping to update content and for sharing their expertise.

If you have any feedback on how to improve content or have updated case study examples for future iterations of this guidance please email: Marine.Coastal.Ecosystems.Team@cyfoethnaturiolcymru.gov.uk with the reference 'GN064 Ecological Enhancement Guidance' and mark it for the attention of Liz Hopley. A supporting video explaining the principles and application of coastal ecological enhancement is also available to accompany this guidance on request.

1. Diben y nodyn cyfarwyddyd

Diben y ddogfen hon yw darparu gwybodaeth a thystiolaeth ar fuddion ac achos gwerth am arian defnyddio gwelliannau ecolegol mewn strwythurau arfordirol. Mae gwahanol ddeddfwriaethau a pholisïau yn cefnogi'r defnydd o welliannau i fioamrywiaeth, gan gynnwys Deddf yr Amgylchedd (Cymru) 2016, Deddf Llesiant Cenedlaethau'r Dyfodol 2015, Cynllun Morol Cenedlaethol Cymru, y Polisi Adnoddau Naturiol, Datganiad Ardal Forol CNC a'r Strategaeth Genedlaethol ar gyfer Rheoli Perygl Llifogydd ac Erydu Arfordirol.

Yng nghyd-destun yr adroddiad hwn, mae ecobeirianneg yn cyfeirio at ddarparu neu addasu asedau arfordirol trwy ychwanegu neu drin strwythurau caled i ddarparu gwelliannau ecolegol a chodi ansawdd ecolegol a bioamrywiaeth asedau arfordirol. Mae'r strwythurau hyn yn bennaf yn y parth rhynglanwol, ond mae rhai yn y parth rhynglanwol a'r parth islanwol bas, a gallai eraill gael eu rhoi yn rhannau llanwol afonydd neu mewn lleoliadau aberol ac afonol. Am y rheswm hwn, mae'r ddogfen hon yn canolbwyntio'n bennaf ar ecowelliannau rhynglanwol. Ni ystyrir yn yr adroddiad hwn bod ecobeirianneg feddal, er enghraifft ychwanegu at draethau neu greu morfeydd heli rhynglanwol, yn fath o brif ddull ecobeirianneg ar gyfer cynlluniau cyfalaf neu gynnal a chadw. Mae penderfyniadau lefel uchel ynghylch priodoldeb a gwerth ecolegol dulliau rheoli caled o'u cymharu â dulliau rheoli meddal / hybrid y tu allan i gwmpas y ddogfen hon. Felly, dylid defnyddio'r ddogfen hon i helpu i bennu pryd ystyrir bod strwythurau ecobeirianyddol yn fuddiol ac yn briodol ar gyfer gwella bioamrywiaeth seilwaith arfordirol.

Nod y ddogfen yw cefnogi sefydliadau cyhoeddus neu breifat sy'n ymwneud â chynllunio, gosod, cynnal a chadw neu ddadgomisiynu strwythurau artiffisial arfordirol, ac sydd am archwilio cyfleoedd i ddefnyddio datrysiadau gwella.
Mae'n rhoi manylion am y wybodaeth, y prosesau a'r ffactorau perthnasol i'w hystyried, ac yn cyfeirio at ffynonellau tystiolaeth allweddol i gefnogi gwneud penderfyniadau ar sail tystiolaeth.

Darperir y wybodaeth hon yn y penodau canlynol:

Pennod 3: **Arfordirol Gwelliannau Ecolegol**, sy'n cynnig adolygiad cychwynnol i amlinellu beth yw gwelliannau ecolegol arfordirol; yr hyn sy'n gyrru eu defnydd; y buddion y gallant eu darparu o ran bioamrywiaeth, a'r fframwaith deddfwriaethol sylfaenol sy'n cefnogi eu defnydd.

Pennod 4: **Mathau o Welliannau Ecolegol Arfordirol**, sy'n nodi pa asedau arfordirol ac aberol sydd â'r potensial i gael eu gwella'n ecolegol a rhai o'r technegau y gellir eu defnyddio ac sydd wedi'u defnyddio. Cynigir detholiad o enghreifftiau o'r DU ar gyfer y rhain.

Pennod 5: **Dylunio Arfordirol Gwelliannau Ecolegol**. Mae'r bennod hon yn rhoi gwybodaeth am gychwyn prosiect gwella, gan gynnwys dewis safle, dewis dull priodol a sut i fonitro a gwerthuso'r budd biolegol.

Pennod 6: **Canllaw i'r Broses Reoleiddio**. Mae'r bennod hon yn cynnig canllaw i'r prosesau rheoleiddio a thrwyddedu sy'n benodol i welliannau ecolegol.

Pennod 7: **Asesiad o Gyfiawnhad**. Mae'r bennod hon yn amlinellu rhai o'r anawsterau gyda chyllido prosiectau a phennu gwerth y buddion.

Pennod 8: Mae'r bennod hon yn cynnig amlinelliad o **gyfathrebu, ymgysylltu ac ystyriaethau diogelwch**.

Pennod 9: Mae'r bennod hon yn cynnig trosolwg o'r wybodaeth allweddol a amlinellir yn y nodyn cyfarwyddyd hwn ac **argymhellion i wella'r defnydd ohono.**

2. Purpose of the guidance note

The purpose of this document is to provide information and evidence on the benefits and value for money case of using ecological enhancements in coastal structures. Various legislation and policies support the use of biodiversity enhancements, including, the Environment (Wales) Act 2016, the Well-Being of Future Generations Act 2015, the Welsh National Marine Plan, the Natural Resources Policy, the NRW Marine Area Statement and the National Strategy for Flood and Coastal Erosion Risk Management (FCERM).

Ecological enhancement in the context of this report refers to the provision or adaptation of coastal assets via the addition or manipulation of hard structures to provide ecological enhancement and increase the ecological quality and biodiversity of coastal assets. These structures are mainly in the intertidal zone, but some are in both the intertidal and shallow subtidal zone, others may be deployed in the tidal reaches of rivers or in estuarine and fluvial locations. For this reason, this document focuses mainly on intertidal ecological enhancements. Soft ecological enhancement, such as beach nourishment or creation of intertidal saltmarsh, are not considered within this report as a primary ecological enhancement approach for capital or maintenance schemes. High-level decisions regarding the appropriateness and ecological value of hard versus soft / hybrid management approaches are outside the scope of this document. Ecological enhancement of hard infrastructure should not replace opportunities for habitat restoration, managed realignment, saltmarsh creation or other nature-based solutions where these are feasible.

Therefore, this document is to be used to inform when eco-engineered structures are considered beneficial and appropriate to enhancing the biodiversity of coastal infrastructure.

The document is aimed at supporting organisations, public or private, involved in planning, installing, maintaining or decommissioning coastal artificial structures, that want to explore opportunities to utilise enhancement solutions.

It provides details on the information, processes and relevant factors to be considered, and points to key sources of evidence to support evidence-based decision-making.

This information is provided in the following chapters:

Chapter 3: **Coastal ecological enhancements** is an introductory review which outlines what coastal ecological enhancements are; the drivers for their use; the biodiversity benefits they can provide and the underpinning legislative framework supporting their uptake.

Chapter 4: **Types of coastal ecological enhancement** identifies which coastal and estuarine assets have the potential to be ecological enhanced and some of the techniques which can be and have been used. These are illustrated with a selection of UK examples.

Chapter 5: **Coastal ecological enhancement design** provides information about starting an enhancement project, including site selection, choosing an appropriate method and how to monitor and evaluate the biological benefit.

Chapter 6: **A guide to the regulatory process** Provides a guide to the regulatory and licencing processes specific to ecological enhancements.

Chapter 7: **Justification assessment** outlines some of the difficulties with funding projects and valuing benefits.

Chapter 8: Provides an outline of **communication, engagement and safety concerns.**

Chapter 9: Provides an overview of the key information outlined in this guidance and **recommendations to improve uptake.**

3. Coastal ecological enhancements

This guidance note forms part of an overview of nature-based solutions for coastal management published by NRW in 2025 centralising currently available resources and literature. Nature-based solutions aim to enhance coastal structures, and work with natural habitats and features to provide a range of benefits to people and the environment.

This guidance provides greater detail of how to 'Green-Grey infrastructure' on the coast, bringing together evidence about of the use of ecological enhancements with a stepped approach to using them in projects.

3.1 What are coastal enhancements?

Artificial structures in coastal areas, such as breakwaters, seawalls, revetments, etc., are required for a wide range of purposes such as flood protection, erosion control or to allow economic and social development. The Shoreline Management Plans (SMPs) identify the best approach to managing risks over the next 100 years from flooding and coastal erosion for individual areas and the wider coast in the UK (Defra, 2006). Work or operations carried out in front of the existing defences to improve or maintain the standard of protection provided by the existing defence line is covered by '*Hold the existing defence line*' policy of the SMPs.

Artificial structures historically lacked drivers to promote biological diversity and so often support different and less diverse communities compared with natural hard-substrate rocky reef habitats. They are normally constructed from quarried rock or synthetic materials (e.g. concrete, steel, plastic) with less favourable surface properties for organisms to attach to than natural coastal rock. They also tend to have homogenous shapes and lack the variety of microhabitats that are known to be important for supporting biodiversity in natural reef habitats (Lawrence PJ et al., 2021 and Aguilera MA et al., 2014) that promote greater species diversity and more mature communities.

Lawrence PJ et al (2021) used remote sensing techniques to compare the structural complexity of natural rocky shorelines to artificial coastal structures at three different scales- fine scale (1–10mm), medium scale (10–50cm) and large scale (1–10m). It was found that natural shorelines displayed greater structural complexity than artificial ones across fine, medium, and large spatial scales. This higher complexity was also more variable between locations, supporting a richer diversity of habitats and correlated directly with higher species diversity. Overall trends found seawalls consistently lacked structural complexity at all scales (~20–40% lower than natural shorelines) and rock armour was deficient at the smallest and largest scales (~20–50% lower).

Ecological enhancements are designed to increase biodiversity and ecological function by increasing structural complexity and habitat heterogeneity. They can be incorporated into new build structures but also existing structures as part of remedial works or retrofitted. They can be applied to an entire coastal scheme, to a discrete section, or to enhance a niche habitat. For example, microhabitats such as rock pools, crevices, holes, flexible canopies and textured surfaces can be created on structures to provide refuge habitats and enable them to function more like natural reefs. These can be drilled, cut or cast into structure surfaces, or 'bolted-on' in the form of prefabricated habitat units.

The materials used in structures can also be selected to promote biodiversity. This could include using natural rock, like local reef habitats, softer rock that may weather more readily, or lower-carbon concretes with recycled components that can reduce the environmental footprint of construction, while providing substrates as good as or better than standard concrete. Finally, target organisms can be transplanted directly onto structure surfaces to give them a head start and pre-empt colonisation by non-native or nuisance species. Ecological enhancement may also help to support reduced flood risk through enhancing the performance of flood defence structures by reducing wave overtopping as well as improve the visual aesthetic of coastal defence structures for coastal users.

It is important to note that the negative impacts of building new structures in the first place are large and the potential biodiversity gains of ecological enhancement those structures are unlikely to compensate for the habitat loss. This is particularly relevant where a hard structure is introduced into a soft sediment habitat.

Under the UK Habitats Regulations (derived from the EU Habitats Directive), competent authorities must undertake a Habitats Regulations Assessment (HRA) for plans or projects that may affect European sites (e.g. SACs, SPA, Ramsar sites).
The key stages are:

1. Screening (Likely Significant Effect)
2. Appropriate Assessment
3. Consideration of alternatives
4. Imperative Reasons of Overriding Public Interest (IROPI)
5. Compensatory measures

The mitigation hierarchy (avoid, minimise, remedy/restore, compensate/offset) (Figure 1) is reflected across these stages.

Following the mitigation hierarchy the following questions should be asked:

1. **Avoid**: Is the infrastructure needed in the first place to avoid impact?
2. **Reduce/minimise**: Can the footprint be minimised?
3. **Restore**: Can the habitat be restored following construction?
4. **Offset**: What habitat creation/ restoration options are most appropriate to offset the damage?

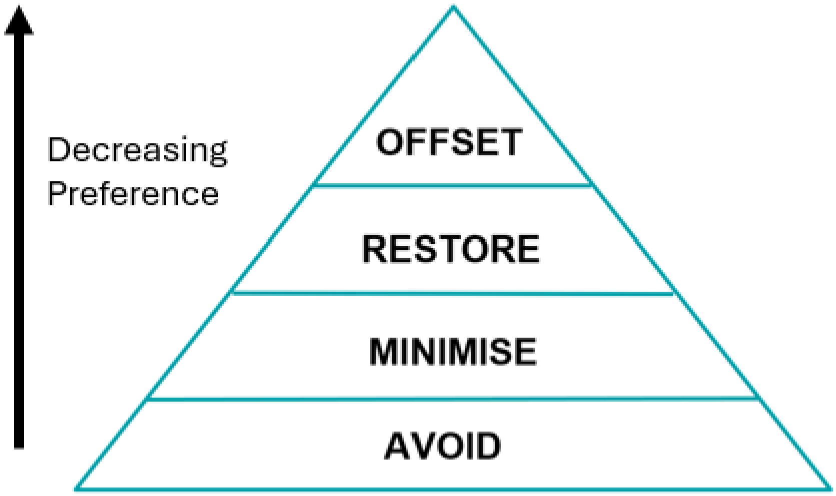


Figure 1 Mitigation hierarchy

Ecological enhancements are treated as:

- **Mitigation** if they avoid or reduce the impact on the European site and allow a conclusion of no adverse effect on integrity for example eco-engineered structures that replace lost function (e.g. roughness, refugia) or incorporate a design that reduces scour, sedimentation, or hydrodynamic effects.
- **Compensation** if they are designed to offset unavoidable damage to maintain the coherence of the Natura 2000/site network. An example is where infrastructure (e.g. cables, foundations) causes permanent loss of Annex I reef or biogenic habitat. The design and mitigation reduce impacts, but residual loss remains. Installation of reef features (e.g. boulders, reef cubes) are placed away from the impact footprint to create new reef habitat.
- They are true enhancements only where they provide **additional biodiversity** benefits beyond what is required to pass the Habitats Regulations test, an example is adding vertipools where no habitat loss has occurred.

Ecological enhancements can be used as a tool to provide a Net Benefit for Biodiversity (NBB). A net benefit for biodiversity is the concept that development should leave biodiversity and the resilience of ecosystems in a significantly better state than before. This is supported by planning policy in Wales. Planning Policy Wales states that planning authorities must maintain and enhance biodiversity, ensuring that development does not lead to significant losses of habitats or species at local or national levels, and that it delivers a Net Benefit for Biodiversity. Authorities must also consider and promote ecosystem resilience. This is driven by Section 6 of the Environment (Wales) Act 2016, which requires public bodies to take action to maintain and improve biodiversity when carrying out their functions in Wales, and in doing so, they should also support resilient ecosystems if this aligns with their proper responsibilities.

NRW Evidence Report 554: Restoring marine and coastal habitats in Wales identifies spatial opportunities and benefits for habitat restoration. The report focusses on six valuable habitats, some of which are relevant for coastal management: intertidal mudflats, coastal saltmarshes, seagrass beds, horse mussel beds, honeycomb worm reefs and native oyster habitat; and their role and the role of restoration in increasing the resilience of marine ecosystems and the multiple benefits it can provide.

The following habitat restoration handbooks are also available:

Saltmarsh Restoration Handbook

Seagrass Restoration Handbook

European Native Oyster Restoration Handbook

Sand Dune Managers Handbook

Restoring Estuarine and Coastal Habitats with Dredged Sediment: A Handbook

To support strategic investment in the marine environment in Wales there is also the option to contribute to strategic initiatives such as MARINE (Marine Resilience and Improvements of Natural Ecosystems) Fund Cymru. MARINE Fund Cymru is a long-term, trustworthy mechanism that invests in programmes and projects that enable, maintain and enhance the resilience of Wales' marine and coastal ecosystems.

If the introduction of artificial hard infrastructure cannot be avoided methods of ecological enhancement can provide biodiversity offsetting/ ecological benefits. The implementation of ecological enhancements needs to be considered at all phases of a capital or maintenance project including planning, design, construction, maintenance and decommissioning stages. It is a multidisciplinary challenge involving engineers, ecologists, policy makers and economists, among other disciplines.

3.2 Climate change, coastal hardening, and simplification

Warmer temperatures, sea level rise and the increase in frequency and severity of storm events have led to increasing risk of flooding and erosion to people, homes and businesses. Across Wales, over 274,000 properties are at risk of flooding from rivers, the sea and surface water according to Flood Risk Management Annual Report 2024 to 2025 . Almost 400 properties also at risk from coastal erosion according to the National Coastal Erosion Risk Map for Wales (2012) The estimated number of properties in Wales predicted to be at risk from coastal erosion over the next 100 years expected to be between 1,262 and 4,053. The National Coastal Erosion Risk Map provides figures over the short, medium and long term, within two management scenarios and within three different sea level rise confidence bandings. Figure 2 illustrates climate change predictions for Wales by 2050 and 2080.

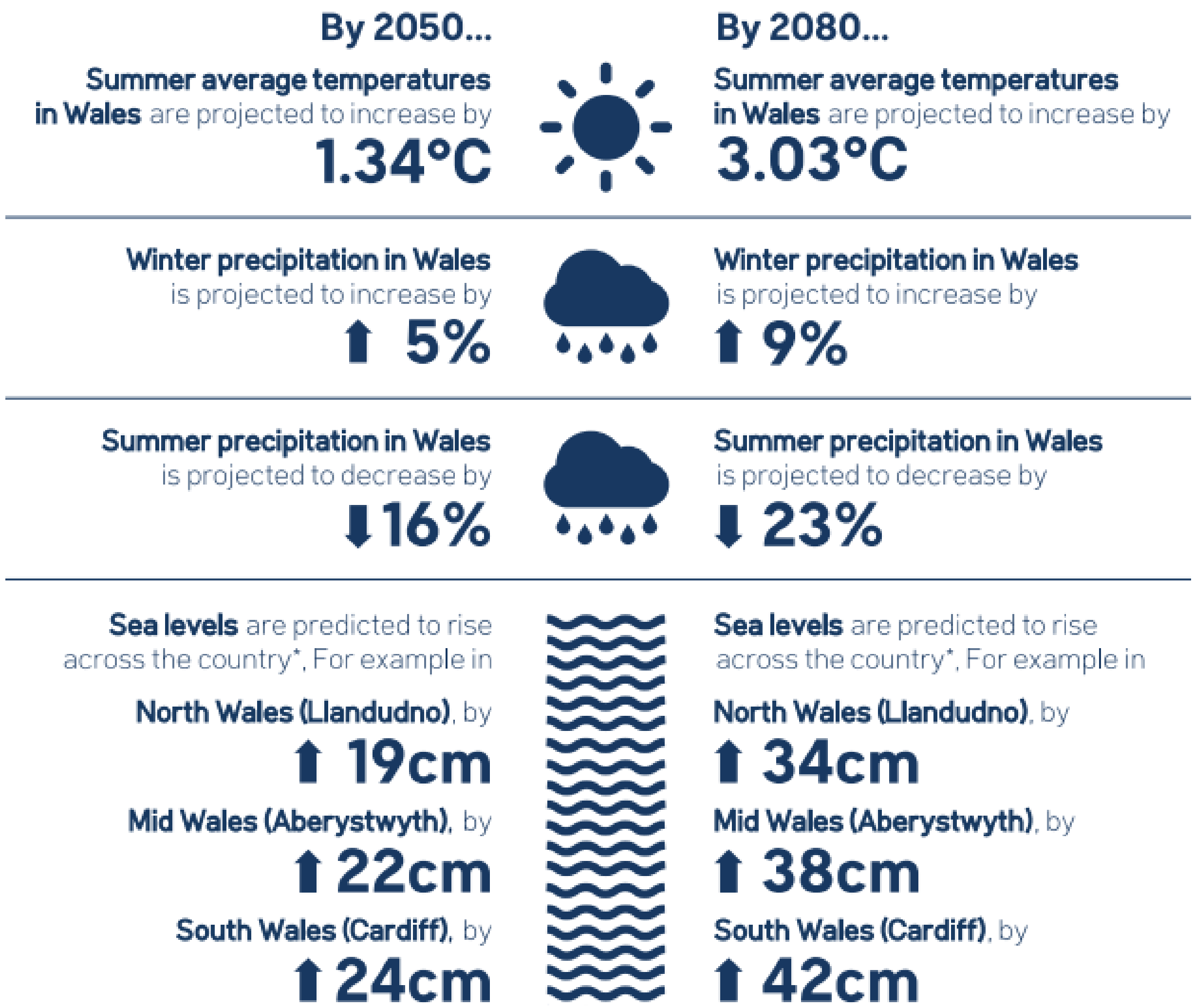


Figure 2 Climate change prediction by 2050 and 2080 taken from UK Climate Projections (UKCP18). Figure extracted from Historic Environment and Climate Changes in Wales. Sector Adaptation Plan, 2020.

Sometimes, hard artificial structures are, and will be in the future, essential to manage these risks. However, the presence of hard structures leads to disruption of natural processes (e.g. water / sediment movement and fragmentation / connectivity between habitats) and increased pressure on coastal habitats leading to loss of habitats within their footprint, and 'coastal squeeze' where retreating habitats (such as saltmarsh) are blocked by hard engineered structures and subsequently shrink until lost completely. Additionally, as sea level rise rocky shores may also be lost to coastal squeeze.

While hard structures add significant amounts of hard substrate open to colonisation by marine organisms and could offer surrogate habitats for intertidal and shallow subtidal reef subject to coastal squeeze, these man-made structures do not always support similar species assemblages to those of natural coastal and marine habitats and are often associated with low biodiversity, nuisance and invasive species (reviewed in Firth et al., 2014).

In Wales, Invasive and Non-Native Species (INNS) are typically associated with ports and harbours, notably the invasive sea squirt *Didemnum vexillum*, whilst coastal defence assets may incorporate the invasive barnacle *Austrominius modestus*. Differences between artificial and natural habitats are closely associated with design and material features related to high inclination, reduced extent, low structural complexity, high homogeneity and different artificial substrate properties. It also reflects the disturbed environmental contexts in which artificial structures are often placed, e.g. in ports with poor water quality, on sedimentary exposed coasts where they are liable to intermittent scouring and burial, disturbance from maintenance operations, etc.

As part of the Ecostructure Project, Lawrence PJ et al. (2021) evaluated how much structural complexity is missing on artificial coastal structures compared to natural rocky shorelines around Wales. Natural shorelines were typically more structurally complex than artificial structures and offered greater variation between locations. However, the results varied depending on the structure type and the scale at which complexity was measured (from 1mm to tens of meters). Seawalls were deficient at all scales (approx. 20-40% less complex than natural shores), whereas rock armour was deficient at the smallest (mm) and the largest (5-10m) scales (approx. 20-50%). The study concluded that hardening shorelines with artificial structures simplifies coastlines, and that "*this lack of complexity represents a considerable deficit in terms of niche provision and is likely to contribute substantially to the lower levels of biodiversity found on artificial structures*". Additionally, Aguilera MA et al. (2014) found that the lack of microhabitats on artificial structures resulted in the absence of several grazers which reflected in lower species richness.

Ecosystem conservation, restoration and management can play a key role in climate change adaptation, buffering societies from the impacts of climate change such as rising sea levels and floods and climate change mitigation, for example, through carbon sequestration and the reduction of greenhouse emissions (Mant, R et al., 2014). Duarte et al. (2020) proposed that restoring the three-dimensional complexity of benthic ecosystems should be key to our global efforts to rebuild marine life.

Based on interpretation and analysis of asset data from DataMapWales Roca et al. (2025) calculated the total length of the Welsh coastline to be 1,824 km, with a total length of 330 km of linear grey assets and 67 other grey asset types including jetties and slipways. This shows the large potential for ecological enhancements in Wales.

3.3 Marine biodiversity

Marine biodiversity in the context of this report reflects the full breadth of intertidal fauna and flora, from supralittoral lichens to invertebrates and fish, and importantly, focussed on marine and coastal biodiversity in Wales and the UK. Biodiversity is measured in numerous ways, most commonly via species presence / absence, abundance, density, species diversity, species richness, evenness, etc. Rather than 'habitats,' marine biodiversity is often described by 'biotopes' that reflect both the combination of the substrate and the biological community. An appropriate set of metrics is essential for defining the baseline status and monitoring change in the biological community following deployment of coastal ecological enhancements.

Marine and coastal biodiversity is an essential and valuable component of Wales' natural resources, providing multiple benefits and ecosystem services. Both in Wales, and globally, marine biodiversity is facing multiple threats from coastal development leading to direct effects such as loss of habitat and indirect effects such as disturbance and reduction in water quality. Simultaneously, climate change effects are elevating water temperatures and sea level rise is driving coastal squeeze that compresses and eliminates coastal habitats, such as saltmarsh, where these are backed by hard infrastructure. NRW is obligated and committed to conserving and enhancing marine biodiversity and supporting the resilience of marine habitats.

Certain habitats and species receive protection directly through legislation or indirectly via associated environmental designations that grant protection via specified areas for vulnerable habitats and species. The Conservation of Habitats and Species Regulations 2017 (as amended by the Conservation of Habitats and Species (Amendment) (EU Exit) Regulations 2019) grants protection for Annex I Habitats and Annex II Species associated with designated sites (National Site Network comprising: Special Areas of Conservation (SAC), Special Protection Areas (SPA) and Ramsar Sites - Wetlands of International Importance) and for European Protected Species (EPS) throughout their distribution.

Regarding European Protected Species refer to Schedule 2 and Schedule 5. In the UK marine environment, this is limited to cetaceans (whales, dolphins, porpoise), pinnipeds (seals) and marine turtles. Other EPS may occur in the vicinity: otter, bats, sand lizard, Killarney fern, etc. and local designations should be reviewed accordingly

Broader habitats and species may be protected by association with Sites of Special Scientific Interest (SSSI) and Marine Conservation Zones (MCZ) pursuant to the Wildlife and Countryside Act 1981 (as amended) and the Marine and Coastal Access Act 2009 respectively. In Wales, the Environment (Wales) Act 2016 lists habitats and species of principal importance for the purpose of maintaining and enhancing biodiversity in Wales; including the following relevant coastal and intertidal features.

Section 7 Priority Marine Habitats:

Littoral Sediment Habitats:

- Coastal saltmarsh.
- Intertidal mudflats.
- Seagrass beds.
- Sheltered muddy gravels.
- Peat and clay exposures

Littoral Rock Habitats:

- Intertidal boulder communities.
- *Sabellaria alveolata* (honeycomb worm) reefs.
- Estuarine rocky habitats.

The above are intertidal habitats since coastal ecostructures are predominantly deployed in the Intertidal zone. A full list of habitats is available in the Environment (Wales) Act 2016 Section 7.

Section 7 Priority Marine Species: most marine priority species are mobile and sublittoral (cetaceans, marine turtles, sharks and rays, etc.) and as such are not appropriate to target with coastal ecological enhancement. However, certain species may still benefit from coastal ecological enhancements, e.g. native oyster, plaice, sole, stalked jellyfish, peacock's tail algae, etc. A full list of species is available in the Environment (Wales) Act 2016 Section 7.

Selection of ecological enhancement solutions must consider the baseline environment that influences the colonisation and composition of rocky shore habitats. Important factors include tidal inundation, wave exposure, salinity, water quality, connectivity to natural rocky habitats that would act as a source site for larval movement to receptor structures, etc. This highlights the need to understand the baseline status of the receptor site and target ecological enhancement appropriately.

Abundance and diversity of marine species is strongly linked to habitat complexity. Certain substrates form complex habitats that often support high diversity and biomass, such as natural rocky shores and intertidal boulder communities. Whilst concrete sea walls present low structural complexity, rock armour provides greater structural complexity and more habitat niches. However, studies compiled by Lawrence PJ et al. (2021) have shown that the similarity of grades of rock armour provide the same habitat complexity and ultimately homogeneity across much of Wales' coastal defence assets. The study encourages the use of multiple grades of rock armour to provide structural complexity like a natural rocky reef and consideration of fine, medium and large-scale topography to provide greater diversity.

Some habitat complexes are created by ecosystem engineers with high abundances of fauna creating 'biogenic reefs. Such organisms include *Sabellaria alveolata* (honeycomb worm), *Sabellaria spinulosa* (Ross worm), *Ostrea edulis* (native oyster), *Mytilus edulis* (blue mussel), *Modiolus modiolus* (horse mussel) and *Serpula vermicularis* (organ-pipe worm). Of these, *Sabellaria alveolata* (honeycomb worm) reefs are an intertidal Priority Habitat in Wales, which comprise aggregations of tubes that create numerous microhabitats and increase habitat heterogeneity. Such biogenic reefs of dense and extensive aggregations form 'biodiversity hotspots' that maintain higher biomass and more complex communities, where otherwise low diversity / low abundance habitats would occur. Retaining and encouraging development of such habitats where feasible will rapidly support the development of high diversity communities.

The objective of coastal ecological enhancement is to enhance marine biodiversity, either:

- to comply with legislative requirements and to support policy targets to reverse the loss of marine biodiversity,
- to act as offsetting for impacts derived from project delivery (e.g. delivery of Flood and Coastal Erosion Risk Management (FCERM) projects), or
- to provide enhancement following the delivery of coastal infrastructure or through the management of assets.

As described above, artificial coastal structures tend to support different and less diverse marine biodiversity to natural rocky habitats. Principally, ecological enhancement of hard coastal structures aims to promote colonisation of diverse communities of marine life onto and around structure surfaces, to enable them to function more like natural reef habitats.

Intertidal and shallow subtidal reef communities of micro- and macroalgae, invertebrates and fishes are key components of the continuum from wider marine to terrestrial food webs. Coastal structures provide settlement and attachment sites for marine algae and colonisation of typical intertidal species including mussels, barnacles, limpets, periwinkles, sponges, tube worms, crabs, anemones, mature and juvenile fish, shrimps, etc. They support broad ecosystem functions and services, including primary production, habitat provision, water filtration and nutrient cycling, such as *Mytilus edulis* (blue mussel) beds. They also often support juveniles and prey of commercially important fishery species.

Some organisms, such as barnacles and macroalgal canopies, can also provide bio-protection for rock surfaces, increasing resilience against erosion. Others are valuable for recreation, tourism and subsistence, e.g. rock pooling, angling or foraging. Therefore, designing artificial structures to support diverse reef communities or specific target species would promote diverse ecosystem functions and services. Coastal ecological enhancement of hard artificial structures aims to target native intertidal communities on a broad scale and deliver opportunities to target priority habitats or species on a case-by-case basis where appropriate.

Coastal developments typically comprise concrete and rock armour of relatively lower biodiversity value than natural rocky habitats. Where coastal structures are developed in soft sediment areas, the addition of hard substrate generally leads to an increase in local biodiversity, albeit losing sedimentary habitat, whereas structures deployed in natural rocky shore habitats lead to a decrease in local biodiversity.

Structures comprised of substrate that is not naturally present (i.e. rock armour and concrete) often develop more juvenile communities with limited stable mature communities associated with increased disturbance (e.g. sediment scouring/burial, trampling, storms damage, maintenance activities, pollution events) due to greater wave exposure and lack of habitat complexity reducing shelter.

Whilst rock armour can develop more diverse intertidal communities on occasions, including full zonation of algae and support *Sabellaria alveolata* aggregations, concrete communities are generally limited to short turfs of green algae and occasional grazers (limpets, periwinkles) on exposed coastlines, but can develop canopy algae in more sheltered areas. Fundamentally, this is linked to smooth surfaces devoid of habitat heterogeneity which lack shelter or suitable attachment substrate. Concrete is also highly basic, with an alkalinity of between 11 and 13, making it relatively unsuitable for marine organisms. Some success has been achieved using lower pH concrete and roughening surfaces to achieve higher abundances and greater diversity.

Marine intertidal communities are strongly influenced by inundation and degree of wave exposure leading to distinct zonation of communities down the shoreline. It is therefore important to factor the tidal elevation of any coastal ecological enhancement to target desired communities and select the appropriate enhancement measure. Often, higher biodiversity on artificial structures occurs lower down the shore where stressors are reduced by greater inundation levels. Further information was subject to research and published by Aberystwyth University in Artificial coastal defence structures as surrogate habitats for natural rocky shores. It is important to balance this benefit with additional habitat loss that may occur relative to the baseline.

Similarly, wave exposure will influence abundance and diversity, and where practicable, ecological enhancements positioned in a mix of exposures and elevations will provide greater local benefits. The EcoStructure Tool BioPredict is available to estimate target biodiversity derived from the baseline site conditions obtained during the Intertidal Biotope Survey. The Tool will therefore support early optioneering of appropriate ecostructures on a site-specific basis. A guide for practitioners on how to use the tool and resources from the Ecostructure project to facilitate eco-engineering and biosecurity of coastal and marine developments supports the use of the project outputs.

The size and shape of microhabitats also affect the type, size and number of organisms that can use them. Therefore, the size and shape of artificial habitats created as part of ecological enhancement actions are also likely to affect biodiversity outcomes. Similarly, ecological enhancement solutions that maintain greater volumes of seawater retention provide more resilience to climatic factors, i.e. more stable temperatures and salinity and consequently develop more stable communities.

In addition, the timing (i.e. season) of artificial structure construction or ecological enhancement interventions is likely to affect what species occupy new surfaces first. This will depend on what larvae and spores are present in the plankton at the time and can have knock-on effects on later arrivals and community development. This is particularly important in locations where non-native invasive species are present. Non-native species are species that exist outside their natural range. They may have arrived through deliberate or unintentional release by humans, transported by vessels (biofouling, ballast water) or through natural processes such as ocean currents.

There are many non-native species in Welsh waters. Most cause no problems, but some do and can harm native marine life, human health and economic activity. These species are called Invasive Non-Native Species (INNS) and further information is available in the Priority Monitoring and Surveillance List for Wales and in the Marine Biosecurity Action Plan for Wales. INNS are a threat because they can disrupt native marine life by preying on or outcompeting native species for food and shelter. As such, biosecurity measures will be essential for the deployment of any ecological enhancements to ensure INNS are not transferred to enhancement sites during construction / operation. Monitoring is also recommended, both to inform the success of establishment, but also to monitor colonisation by any INNS, which often take advantage of new structures and outcompete native flora and fauna and risk spreading beyond the initial attachment site.

3.4 Legislative and policy drivers

Several legislative and policy drivers require and manage the deployment of coastal ecological enhancement. Principle statutory instruments and key policy are listed below.

Key legislative drivers – Ecological Enhancement Delivery:

- **Environment (Wales) Act 2016** – The Act sets a duty on NRW to adopt Sustainable Management of Natural Resources (SMNR) in the exercise of its functions. Section 6 also enacts a duty on NRW to conserve and enhance biodiversity and promote the resilience of ecosystems, with a focus on Priority Habitats and Priority Species.
- **Well-Being of Future Generations Act 2015** – the Act aims to improve the social, economic and cultural well-being of Wales by placing a duty on public bodies to think in a more sustainable and long-term way. The Act puts in place seven well-being goals that public bodies must work to achieve and take into consideration across all their decision-making. NRW have developed corresponding well-being goals, published in Our well-being statement.

Key policy drivers – Ecological Enhancement Delivery:

- **Welsh National Marine Plan: Welsh Government, 2019** – Policy ENV_01 aims to ensure that biological components of ecosystems are maintained, restored where needed and enhanced where possible, to increase the resilience of marine ecosystems and the benefits they provide. Supporting the implementation of the Welsh National Marine Plan: Enhancing marine ecosystems explores wider options for the implementation of the ‘enhancement’ aspect of this policy.
- **Natural Resources Policy: Welsh Government, 2017** – sets out three national priorities for the management of our natural resources. First and foremost is the requirement to deliver nature-based solutions, such as deployment of ecological enhancements.

- **NRW Area Statements: Marine Area Statement – **seeks to improve resilience in the marine environment to support climate change adaptation and encourages the use of ecological enhancements.
- **National Strategy for FCERM: Welsh Government, 2020** – encourages the use of natural flood management techniques through nature-based solutions, such as delivery of coastal ecological enhancements.

Key legislative requirements – Consenting and Regulation:

- **Marine and Coastal Access Act 2009** – enforces the protection and regulation of the marine environment. The Act requires deposits or removals below Mean High Water Springs (MHWS) to be consented by NRW's Marine Licensing Team.
- **Conservation of Habitats and Species Regulations 2017** – requires Habitats Regulations Assessment (HRA) of any proposals that have the potential to affect the National Site Network, that are not necessary for the management of that site. The National Site Network, previously referred to as 'European Sites' / 'Natura 2000 Network', comprises Special Areas of Conservation (SACs), Special Protection Areas (SPAs) and proposed and candidate sites thereof. It does not apply to Sites of Special Scientific Interest (SSSI). It is Government policy that this also includes Ramsar Sites (Wetlands of International Importance).
- **Marine Works (Environmental Impact Assessment - EIA) Regulations 2007** – provides a framework and regulation for protection of the environment in the marine environment below MHWS.
- **Town & Country Planning (EIA) (Wales) Regulations 2017** – provides a framework and regulation for protection of the environment in the terrestrial environment above MLWS.
- **The Environmental Permitting (England and Wales) Regulations 2016** set the legislative framework for industrial and waste installations which have the potential to cause harm to human health or the environment, and the relevant permitting practises and structures associated with such activities.
- **Wildlife and Countryside Act 1981 (as amended)** – provides for the creation and protection of Special Sites of Scientific Interest (SSSI) for biodiversity and geological diversity.
- **Water Environment (Water Framework Directive) (England and Wales) Regulations 2017** – requires protection of WFD water bodies (including coastal waters to 1km offshore) and sets targets for the achievement of Good Ecological Status, establishes Shellfish Water Protected Areas and supports the identification and protection of higher sensitivity habitats.
- **Bathing Water Regulations 2013 (as amended)** – ensures water quality standards are met at Bathing Water beaches around Wales.
- **Historic Environment (Wales) Act 2016** – ensures the protection of cultural heritage and archaeology within Wales.
- **Marine Strategy Regulations 2010** (implementing the Marine Strategy Framework Directive) – supports the monitoring and control of marine INNS.

3.5 Ageing assets

As companies look to adapt their assets to cater for the impacts of climate change, a particular challenge is the approach taken to ageing assets which range in age, environmental exposure, usage, some may have been designed and built to different/superseded design codes and may have bespoke maintenance regimes – all of which combine to determine how an asset may respond to a changing climate.

Old deteriorating structures are often good for biodiversity. For example, fish, crabs, snails, anemones etc. refuge in the crevices created when the mortar between wall blocks weathers away. When the joints are repointed, that habitat is lost (Moreira J. et al., 2007). Thought should be given about how those habitats could be replaced (e.g. through bolt-on habitat units or by casting into the mortar used in the repairs) when repointing is needed for structural integrity.

Ageing assets do present an opportunity for the introduction of ecological enhancements as part of remedial, refurbishment and upgrade works, whether these be modifications to or replacement of existing assets. Therefore, it is crucial that ecological enhancements are considered on all project types to ensure the maximum benefits are realised. To put this in context, some examples are presented below:

- Where an aged asset is to be replaced with a new structure, ecological enhancements can be embedded within the design of the new structure from the outset.
- Where an existing asset is to be upgraded (e.g. raising the cope level of a wall), consideration can be given to ecological enhancements for the new part of the asset as well as what can be introduced as part of the works to the existing asset. For example, use may be made of plant and equipment on site (e.g. concrete drilling equipment) to cost effectively add ecological enhancements to the existing structure. When ecological enhancements are considered at a very high shore part of structures, it is essential to understand the benefits to be gained as often the higher up in the structures the more limited the benefits are.
- Where remedial or refurbishment works are required for ageing assets, consideration can be given to ecological enhancements being incorporated in these works. For example, works to improve durability and extend the life of reinforced concrete structures are common for coastal assets. These works can, if well planned, include ecological enhancements which may contribute to the life extension of the asset.

In summary, many ageing assets will require works in the short to medium term. The introduction of ecological enhancements within all these works, whether they are remedial, refurbishment or upgrade works, is possible and should be considered on all project types to ensure the maximum benefits and value are realised.

4. Types of coastal ecological enhancement

This chapter identifies which coastal and estuarine assets have the potential to be ecological enhanced and some of the techniques which are used.

4.1 Coastal assets

Examples of the type of grey structures where ecological enhancement could be applied are shown below. Enhancements can be added to structures at any stage during the design life of the structure but ideally should be included at the design stage.

4.1.1 Outfalls

Figure 3 An outfall Source: [Coldharbour outfall extension (2018) – Southeast Coastal Group (se-coastalgroup.org.uk)]()

4.1.2 Open channels (tidal)

Figure 4 An open channel Source: [A bend in the river, Bridgend - geograph.org.uk - 1692133 - Bridgend - Wikipedia]()

4.1.3 Walls

Including concrete and masonry walls.

Figure 5 A seawall Source: [Sea Wall - Coastal Erosion Management, Criccieth, North Wa… | Flickr]

4.1.4 Embankments

Including concrete faced, gabions, rock armour and riprap engineered embankments.

Figure 6 An embankment Source: [River Tawe Swansea 2017 05 11 #28 | Gareth Lovering | Flickr]

4.1.5 Ramps and slipways

Figure 7 A ramp Source: [We walked along to the concrete access ramp which enables … | Flickr]

4.1.6 Weirs

Figure 8 A weir Source: welsh weir - Bing

4.1.7 Steps and terraced revetments

The main difference is that with terraced revetments the main purpose is coastal defence, rather than public amenity.

Figure 9 A terraced revetment Source: Porthcawl town beach re-opens to the public after £3m improvements to sea defences - News from Wales

4.1.8 Groynes

Including rock armour, riprap and concrete groynes. Rock and concrete armour revetments and breakwaters can also be included here.

Figure 10 A rock groyne Source: Rock Groyne © N Chadwick cc-by-sa/2.0 :: Geograph Britain and Ireland

4.1.9 Spillways

Figure 11 A spillway Source: Llyn Brianne Spillway | turbostar171 | Flickr

4.1.10 Bridge abutments

Figure 12 A bridge abutment Source: Blue Bridge (Jubilee) At Queensferry Deeside, Wales, UK. Queensferry is a town and electoral ward in Flintshire, Wales, lyi… | Photography, Bridge, Portrait photo (pinterest.com)

4.2 Ecological enhancement techniques

The following notes apply to all nine techniques discussed below:

i. These examples are not exhaustive but provide a reference or point of discussion on the benefits and challenges that may be encountered while incorporating ecological enhancements to existing structures. The examples included are taken from several studies. The issues discussed in the following tables may or may not be all realised for other specific projects.

ii. The costs quoted are sometimes based on volunteer/research organisations undertaking the work. If the work was to be done by a contractor, additional costs such as overheads would apply.

Technique 1 – Drill-in pits, grooves and crevices

Description

Retrofitting rock armour or concrete surfaces with habitat features by drilling small and varied diameter holes - pits (A), grooves (B) and/or recessed crevices. The aim is to provide water retaining features and/or refuge and/or secure anchor points which improve ecosystem heterogeneity.

Figure 13 Technique 1 Drill-in pits (left), grooves and crevices (right). Pits- Source: Hall et al., 2018 and Grooves-Source: Hall et al., 2018.

Effectiveness: benefits assessment

- Pits in granite and limestone rock armour: improved ecological outcomes (increase in species diversity) were found after 12 months in the trial at Runswick Bay and Poole Bay (Naylor et al, 2017).
- Increase in species diversity compared with business as usual in both holes and grooved treatments. 6 of 10 functional groups were unique to the drilled pits (Firth et al.,2014).
- The increase in species diversity was greatest on the grooved treatments (Naylor et al. 2017).
- Species of commercial importance were only found in the enhanced areas demonstrating that this technique provided supporting ecosystem services (Naylor et al, 2017).
- Limestone had higher overall species richness and diversity than the granite rock armour (Naylor et al, 2017).
- Wider environmental benefits – they facilitate climate change resilience through supporting biodiverse ecosystems.

Challenges: limitations and risks

- Need to be certain that structural integrity / durability will not be affected – may require a sacrificial layer of concrete.
- Over time, effects lessened as the pits were filled with sessile species reaching a biodiversity maximum.
- Due to local hydrodynamics the bed level of the foreshore rose unevenly resulting in some features being 'lost'.
- Since many experiments are at the plot scale rather than at the full structure, it's unclear whether interventions enhance biodiversity or aggregate organisms already on the structure.

Cost

- Cost of adding the holes varies by material type. Limestone was less expensive to retrofit (£10/m3) than granite (£55/m3) (Naylor et al, 2017). Costing was based on the time taken to drill holes. The harder the material, the longer it takes to drill holes.
- Additional cost of adding the holes ranged from 15% to 100% more expensive than business-as-usual (Naylor et al, 2017).

Maintenance and asset management considerations

- The size and density of the features must be small enough to not negatively impact on the performance of the rock armour or structure.
- Pits of 14mm and 22mm diameter to a depth of 25mm and separated by 10cm were tested in Plymouth Breakwater (Firth et al.,2014).
- Arrays of 4 holes, 16mm diameter by 20mm deep and score marks of 2mm x 600mm long x10mm above and below a central 1mm X 600mm long by 20mm deep groove were tested in Runswick Bay and Poole Bay (Hall et al, 2018). It should be noted that this study was undertaken at pilot-scale. The number of holes shall be appropriate for the asset / structure in hand.
- No difference was found in species richness between 14/22mm pits (Firth et al.,2014)

Consenting

- Likely consenting route: drilling (removal activity) – likely no marine licence when undertaken on an artificial structure; confirm with NRW Marine Licencing Team (MLT) in advance. Any sacrificial layer would need to be integrated into the design or would require a marine licence to deploy post-development.
- The habitat creation assisted approval of the Runswick Bay coastal defence scheme by the Marine Management Organisation and Natural England, as it is within a Marine Conservation Zone.

Technique 2 – Cut-in rockpools

Description

Creation of artificial water-retaining depressions ‘pools’ on rock and concrete armour units using a variety of methods, for example:

A. Cores, originally created to test boulder density, were filled to create 10cm deep rock pools on an intertidal breakwater (Firth et al.,2014).
B. Drill-cored rock pools of 15cm diameter and depth of 5cm and 12cm on the horizontal surface of granite boulders on a breakwater (Evans et al., 2016).

The above techniques can be interpreted as active interventions. Passive interventions to achieve the same goal of retaining water include rotation of rocks during placement to benefit from the natural heterogeneity of existing depressions (Macarthur et al., 2020).

Figure 14 Technique 2 Cut-in rockpools (Left) Cores [Source: Firth et al.,2014], (right) drill-cored rock pools [Source: Evans et al., 2016]

Effectiveness: benefits assessment

- Pools supported greater number of species compared to adjacent surfaces, which in turn increased diversity.
- Pools supported comparable number of species to natural rockpools.
- Species diversity and resilience positively correlated with volume of seawater retention.
- A total of eight species colonised the boulders (pools and emergent rock) throughout the experiment. Pools supported significantly greater species richness (including barnacles, shrimp, gastropods and algae) than emergent substrata (barnacles and gastropods only) (Firth et al.,2014).
- Wider environmental benefits -the intervention facilitates climate change resilience through supporting biodiverse ecosystems.

Challenges: limitations and risks

- Artificial pools supported different communities of marine life compared to natural rock pools (B).
- Only five out of nine cores retained water sufficiently to function as rock pools (Firth et al.,2014).
- Demonstration project, a fully replicated long-term experiment is essential to accurately assess patterns of distribution and abundance in relation to the different habitat types (Firth et al.,2014).
- The potential for habitats to reach a biodiversity maximum. Research found this in some (but not all) of the drill-cored pools after six years – *Sabellaria* plugged some of the cores representing establishment of a Priority Species due to the intervention. Reported in Firth L.B., et al. (2020).
- Changes in coastal processes occasionally resulted in pools being intermittently buried, scoured and unburied, representing a need to understand local conditions and future baseline. Burial and scour will lead to the successional trajectory being re-set cyclically, rather than reaching stable mature communities, whereas pools on sheltered surfaces become filled with sediment permanently

Maintenance and asset management considerations

- Pools were intermittently buried by mobile sediment and retained sand/pebbles following storms but emptied naturally and continued to function as rockpools, but sheltered pools inundated with sediment, thus failing to function as rock pools, instead supporting muddy habitats.

Cost

- It took two workers approximately. two hours to in-fill nine cores. No skilled labour was required.
- Approx. £50/pool.

Consenting

- Likely consenting route: drilling (removal activity) – likely no marine licence when undertaken on an existing artificial structure; confirm with NRW MLT in advance. New drilled structures (deposit activity) would need to be integrated into the design prior to consenting, or post-development deployment of any new pre-drilled structures would require a separate marine licence

Technique 3 – Cast-in rockpools

Description

Creation of artificial water-retaining depressions 'pools' cast into concrete poured into the base of energy dissipating units with opening diameter 13–14 cm, bottom diameter 10.6 cm and 10–12 cm depth (Firth et al., 2016).

Figure 15 Technique 3 cast-in rockpools [Source: Firth et al.,2014]

Effectiveness: benefits assessment

- Pools supported greater number of species compared to adjacent surfaces, which in turn increased diversity.
- Pools supported comparable number of species to natural rock pools.
- Species diversity and resilience positively correlated with volume of seawater retention.
- A total of eight species colonised the boulders (pools and emergent rock) throughout the experiment. Pools supported significantly greater species richness (including barnacles, shrimp, gastropods and algae) than emergent substrata (barnacles and gastropods only) (Firth et al.,2014).
- Wider environmental benefits - the intervention facilitates climate change resilience through supporting biodiverse ecosystems.

Challenges: limitations and risks

- Demonstration project, a fully replicated long-term experiment is essential to accurately assess patterns of distribution and abundance in relation to the different habitat types
- Changes in coastal processes occasionally resulted in pools being intermittently buried, scoured and unburied, representing a need to understand local conditions and future baseline. Burial and scour will lead to the successional trajectory being re-set cyclically, rather than reaching stable mature communities, whereas pools on sheltered surfaces become filled with sediment permanently.

Maintenance and asset management considerations

- Pools were intermittently buried by mobile sediment and retained sand/pebbles following storms but emptied naturally and continued to function as rockpools, but sheltered pools inundated with sediment, thus failing to function as rockpools, instead supporting muddy habitats with associated fauna.

Cost

- Pools (80) were created using a digger, truck and cement mixer, and three hired contractors over five days; approx. £32 per pool.

Consenting

- Likely consenting route: New cast-in structures (deposit activity) would need to be integrated into the design prior to consenting.

Technique 4 – Cast-in textured, grooved and creviced concrete surfaces

Description

Use of concrete mix that enhances the growth of marine flora and fauna (Perkol-Finkel and Sella, 2014) and texture forms which induces rich marine growth.
The textured features can be imprinted in precast elements which can be retrofitted or cast in-situ using textured formwork.

Examples where this technique has been used are:

(A) ECOncrete® piles and jackets.
(B) Textured concrete outfall pipe- Outfall pipe on Hannafore beach in West Looe, Cornwall.
(C) Textured Seawall / riverwall- Ecoformliner - textured seawall at Portsea Island [Source: Coastal Partners https://coastalpartners.org.uk/]

(A)

(B)

(C)

Figure 16 Technique 4 Cast-in textured, grooved and creviced concrete surfaces

Maintenance and asset management considerations

- No different to business as usual.

Challenges: limitations and risks

- Limited if integrated into the design from the outset.
- Design will require small amounts of additional concrete to create texture.
- Formwork more complex and costly. Modifications may be required to the design to facilitate removal of the concrete formwork.
- Longevity/durability of the pattern in very exposed sites, e.g. to waves or to abrasion.

Effectiveness: benefits assessment

- Ecological – increased animal abundance and algal species diversity.
- Jackets showed 70-100% live cover of marine life compared to 20-50% on controls (3 months). Jackets showed 90-100% live cover of marine life compared to 40-85% on controls (14 months) (Perkol-Finkel and Sella (2015)).
- Engineering - the biology may improve asset resilience to weathering-related deterioration (Naylor et al. (2017)).
- Social – good acceptance from the public which felt that this type of finish was likely to provide more ecological value than smooth concrete (Naylor et al. (2017)).
- Wider environmental benefits – they facilitate climate change resilience through supporting biodiverse ecosystems.

Cost

- The cost of the textured tiles for Hannafore project was ~£1000/m2.

Consenting

- Likely consenting route: structures would need to be integrated into the design prior to consenting, or post-development deployment of any new structures would require a separate marine licence.

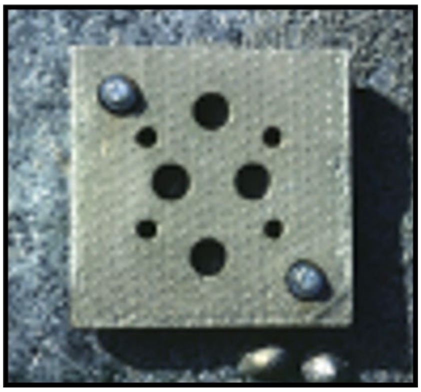
Technique 5 – Bolt-on precast panels and tiles

Description

Concrete tiles with enhanced complexity (holes, grooves, texture, etc.) that can be attached to the rocky outcrops and armour units of groynes, rock breakwaters, rock revetments, concrete walls and other concrete structures. The increased complexity encourages colonisation and increased biodiversity.

As a similar principle with increased complexity, 3D printed concrete modular tiles mimic some of the features that are found in natural rocky shores which provide food and shelter and aim to create a balanced ecosystem.

The panels/tiles can be built with a concrete mix that enhances the growth of marine flora and fauna (Perkol-Finkel and Sella, 2014).



Tile with holes to add complexity

Mumbles Sea-Hive. [Source: Ruth Callaway, Swansea University]

Living Seawall panels

ECOncrete® panels in a seawall

Figure 17 Technique 5 Bolt-on precast panels and tiles

Effectiveness: benefits assessment

- Improves aesthetics - good acceptance from the public which felt that this type of finish was likely to provide more ecological value than smooth concrete (Naylor et al. (2017)).
- Living Seawall panels - improved water quality.
- Living Seawall panels - rough surface reduces overtopping.
- Engineering - the biology may improve asset resilience to weathering-related deterioration (Naylor et al. (2017)).
- Wider environmental benefits – they facilitate climate change resilience through supporting biodiverse ecosystems.

Challenges: limitations and risks

- Limited if integrated into the design from the outset.
- Securely fixing panels to structures.
- Sediment getting trapped in pools (this applies to most interventions with depressions in them, depending on the factors such as surrounding habitat and wave exposure).
- H&S issues with members of the public accessing the panels.
- Design will require small amounts of additional concrete to create habitat features.
- Formwork more complex and costly.

- Longevity / durability of the pattern in very exposed sites unknown, e.g. to waves or to abrasion.

Maintenance and asset management considerations

- Panels could increase durability of structure.
- Inspection and maintenance of structure covered by panels.
- Potential risk of waves pulling the panels/tiles off as some are raised away from the wall.
- Large pools created in the Living Seawall panels seawall could trap litter.

Cost

- Living Seawall panels - £175 per unit (note these are currently manufactured in Australia so delivery cost and carbon footprint could be significant).
- Additional cost of design and production of textured formwork than business as usual. From Naylor et al. (2017), in the Hartlepool example, it cost an extra £8-£30 per m^2 compared to plain cast formwork.
- Sea-Hive panels £100-150 per panel for patterns from Reckli catalogue https://www.reckli.com/en/ (over 200 designs). Additional cost for bespoke Sea-Hive formliners and construction.
- Living Seawall panels have a typical design life of 20 years.

Consenting

- Likely consenting route: structures would need to be integrated into the design prior to consenting, or post-development deployment of any new structures would require a separate marine licence.

Technique 6 – Bolt on precast vertical pools

Description

Vertipools are cast marine concrete unit products designed to be attached to sea defences to retain seawater as the tide recedes – they are shaped to replicate a range of natural microhabitats for shoreline species and are simply fixed with bolts or brackets and non-toxic waterproofing resin (Naylor et al. (2017)).

To optimise ecological function, it is recommended:

- They are fitted in groups of 5 with around 10m between groups, this provides pockets of high-density habitat along the length of the seawall. A 100m seawall may therefore support 50 Vertipools (based on manufacturer recommendations).
- Placement at around MLWN may have greatest potential for ecological gains. Future sea level may be considered when deciding the height at which Vertipools are installed. A range of exposures to different environmental conditions (e.g. waves and wind) may be beneficial. In any case, the optimal height would depend on the objectives pursued.

Figure 18 Technique 6 – Bolt on precast vertical pools

Effectiveness: benefits assessment

- Ecological - These and other similar structures have the capacity to provide habitat where previously there was little or no water-retaining habitats and could support locally significant populations.
- There is potential to adapt the pools to mimic specific habitat for individual species or target communities.
- Where coastal squeeze becomes significant Vertipools could become accessible to species currently surviving in natural pools.
- Wider environmental benefits – they facilitate climate change resilience through supporting biodiverse ecosystems.
- Social – they allow engagement with the wider public in the processes e.g. design and manufacturing, underlying science and local natural environment (this could also apply to other techniques).
- After 3 years, they increased species diversity and attached mobile fauna including crabs and fish.

Challenges: limitations and risks

- The most suitable place for applying this measure is where artificial hard structures either replace or are adjacent to existing rocky shore habitats. However, they may still present ecological benefits on structures far from natural reefs, which are not getting naturally colonised.
- H&S issues with members of the public climbing on the Vertipools.

Maintenance and asset management considerations

- Durable enough to resist wave and tidal action for >3 years in moderately exposed and exposed settings.
- No detrimental effect on the engineering performance of the defences.
- Units breaking off and leaving the metal rods attaching the panels exposed.
- To be installed at a density and of a size that would not restrict inspections and maintenance practices.
- Not suitable for places with boat traffic due to their pronounced shape.

Cost

- £500-£1,000 per unit for construction and installation depending on environment. Should reduce with economies of scale.

Consenting

- Likely consenting route: structures would need to be integrated into the design prior to consenting, or post-development deployment of any new structures would require a separate marine licence.

Technique 7 – Bolt on green wall modules

Description

Green wall modules: Plastic modules filled with soil and faced with coir (coconut fibre) and wire mesh. Designed for use on steep intertidal embankment walls at various scales (Francis et al. (2015)). Can be scaled according to requirements and act as stepping stone habitats in coastal, riverine or estuarine habitats.

Figure 19 Technique 7 – Bolt on green wall modules

Effectiveness: benefits assessment

- Ecological - Successful recruitment and colonisation of plants in the modules. Greatest colonisation was seen in more sheltered locations. The wall modules on the 45-degree slope had the most vegetation cover, outperforming the modules on the vertical slopes.
- Ecological – designs can incorporate multi-level retaining features to support localised saltmarsh colonisation and / or fish spawning features. Can create ‘stepping-stone’ habitats to address habitat fragmentation.
- Social – people recorded their perceived benefits of the vegetation as provision of habitat and aesthetic improvement of the walls.
- Test completed over 14 months. Significant peak in vegetation during spring/summer months. Peak cover after 5-9 months (from January).

Maintenance and asset management considerations:

- The cultivated vegetation may need to be maintained so that it does not look too unkempt or neglected.
- Where possible place modules at an angle to presumably allow greater deposition of seeds with fluctuations in flow, along with increased potential for retention of sediment, organic materials and moisture.

- Where possible, use stainless steel brackets, as these have a longer lifetime and less risk plastic pollution.

Challenges: limitations and risks

- Modules should be installed at an angle, i.e. not vertical, to encourage a good level of plant coverage and species richness.
- Some people remarked the untidy appearance, potential wall damage and the risk of trapping litter.
- Vegetation establishment on the vertical wall modules was disappointing; trough features more effective.

Cost

- Installation: < £4,000 for 40 modules.

Consenting

- Likely consenting route: structures would need to be integrated into the design prior to consenting, or post-development deployment of any new structures would require a separate marine licence.

Technique 8 – Drop-in prefabricated units

Description

Precast concrete units which mimic one or multiple habitat enhancements such us rockpools, pits, crevices, etc. within each unit. They can be incorporated into riprap structures, rock revetments, rock groynes and rock breakwaters.

BIOBLOCK (A) is a large, precast habitat-enhancement unit comprising multiple habitat-enhancement types (rock pools, pits, crevices) that would be present on the boulders of a structure (Firth et al., 2014).

Tide Pool Armour (B) is a modular water-retaining unit that mimics natural rockpools

(A) BIOBLOCK

(B) Econcrete Tidal Pool

(B)

Figure 20 Technique 8 – Drop-in prefabricated units showing a BIOBLOCK on the left [Source: Naylor et al., 2017] and an Econcrete Tidal Pool on the right [Source: Coastal Partners https://coastalpartners.org.uk/].

Effectiveness: benefits assessment

- Ecological – BIOBLOCK supported over twice as many species as adjacent boulders over 12 months and improved species diversity. The tide-pools presented a richer community when compared with the rocky area surrounding it which was very poor in biological findings. It should be noted that each individual habitat type did not on its own increase diversity, it was the combination of all three habitats on the BIOBLOCK that increased diversity. The greater volume of retained seawater reduces fluctuations in temperature and salinity allowing more resilient communities.
- Wider environmental benefits – they facilitate climate change resilience through supporting biodiverse ecosystems.
- The results reported after 12 months showed that more species than at adjacent boulders were present.
- The results reported 9 months post-installation demonstrated that tide-pools had a live coverage of 89-100% of the water-retaining portions of the pools (live coverage was made up of mostly filamentous green algae) (Petrol-Finkel and Sella, 2015).

Maintenance and asset management considerations

- They can be installed during construction or retrospectively.
- BIOBLOCK should last >10 years (Naylor at al., 2017).
- Deposition may need to be removed after large storms if not cleared naturally.

Challenges: limitations and risks

- Covered in sand following massive deposition during winter storms.
- Suitable access and large lifting equipment would be required.

Cost

- Each BIOBLOCK costs approximately £2,000 for mold, concrete, and delivery.
- The BIOBLOCK is between 9-13 times more expensive per unit compared to business-as-usual rock armour used in rock groynes.
- The installation would require lifting equipment and appropriate access to undertake the lifting operations – costs vary.

Consenting

- Likely consenting route: structures would need to be integrated into the design prior to consenting, or post-development deployment of any new structures would require a separate marine licence.

Technique 9 – Miscellaneous

Description

Several broader, more strategic enhancement opportunities are presented here should the opportunity to deliver wider gains be present at a particular site; typically associated with Capital Projects or strategic programmes.

- **Synthetic free hanging ropes** attached to a structure such as a pier. Provides habitat complexity and attachment opportunities to support colonisation.
- **Native oyster colonisation** in floating or seabed structures supported by deposition of old oyster / mussel shells in the local vicinity to create optimum settlement stratum: https://nativeoysternetwork.org/ / https://wild-oysters.org/

- **Seagrass restoration** - planting seagrass seeds sourced from donor sites to support colonisation of existing, historic and other suitable seagrass sites: https://www.projectseagrass.org/
- **Kelp Restoration** – support the restoration and expansion of kelp parks / forests through better management: https://sussexwildlifetrust.org.uk/helpourkelp Alternatively, kelp may be transplanted / seeded onto structures in appropriate locations to deliver gains earlier.
- **Advanced Mooring Systems** - adapting local moorings to neutrally buoyant designs to reduce local mooring chain abrasion impacts on seagrass beds: https://thegreenblue.org.uk/wp-content/uploads/2021/01/The-Green-Guide-to-Anchoring-Moorings.pdf Potential to use BIOBLOCK or similar as mooring block

Maintenance and asset management considerations

- Synthetic free hanging ropes – may require routine replacement.
- Oyster Habitat Restoration - routine maintenance, potential third-party support. Monitoring programme.
- Seagrass Restoration / Advanced Mooring Systems – routine maintenance, potential third-party support. Monitoring programme.
- Kelp Restoration – monitoring programme.

Challenges: limitations and risks

- Synthetic free hanging ropes – may initially not be aesthetically pleasing to local community.
- Synthetic free hanging ropes could become entanglement hazard or debris if dislodged.
- Synthetic free hanging ropes could be a source of microplastic pollution
- Oyster Habitat Restoration – Biosecurity requirements, Crown Estate licence / seabed lease and aquaculture authorisation.
- Seagrass Restoration – consent and biosecurity requirements.
- Kelp Restoration – likely to require change to local byelaws and regional consultation.

Effectiveness: benefits assessment

- Oyster Habitat Restoration – success in Angle Bay, Pembrokeshire that now provides spat for other restoration projects.
- Seagrass restoration – success around the UK.
- Kelp Restoration – early stages but positive signs; Sussex.

Cost

- Habitat restoration typically large-scale and resource intensive, greater costs than standard interventions.
- Potential to link with NGOs, charities and wider funding opportunities.

Consenting

- Likely consenting route: any deposit or removal activity below MHWS (not included within a consented design) may require a marine licence supported by environmental assessments.

4.3 Case studies

Most coastal and estuarine ecological enhancements implemented in the UK to date have taken the form of innovative prototypes, pilot schemes, or focused research projects. Although many of these have been delivered at a limited scale or within short project timelines, they have generated valuable learning and demonstrated strong potential. Expanding these enhancements to a larger footprint—such as across an entire scheme—opens opportunities for wider ecological gain. The upscaling challenges range from procurement constraints (cost, buildability, unknown hydraulic/environmental performance, influence on the structural integrity of the underlying asset, as well as the need for more robust ecological benefit assessment. These are increasingly recognised as areas where continued collaboration, research and innovation can drive confident, sustainable delivery at scale.

Appendix 1 outlines case studies of seven ecological engineering techniques applied to coastal and estuarine structures, drawing on peer-reviewed studies and demonstration projects in the UK, Europe, Australia and the USA. Across these case studies, microhabitat features (pits, grooves, crevices, pools, textured concrete and modular elements) increased species richness and functional diversity without compromising engineering performance. Costs were found to vary by material and approach—from marginal additions for drilling through to higher unit costs for bespoke precast units—but can be justified where biodiversity improvements, community benefits and long-term resilience are achieved.

Key lessons learnt are as follows:

- Embed ecological enhancements at concept/design stage to avoid retrofitting overheads and ease consenting, particularly in protected areas.
- Plan monitoring (≥12–24 months; longer for plant modules) and adaptive management to optimise designs.
- Engage communities—visible enhancements can deliver education and social license. Design for durability in high-energy sites (tile protection, robust fixings, hydrodynamic forms).
- Ecoenhancements can be vulnerable to physical damage from harsh coastal conditions. Design features to be durable for high energy sites and implement monitoring programmes to assess degradation and repair procedures.
- Retrofitting small features is low-cost and low-risk, especially on limestone; bespoke precast units offer larger ecological gains at higher unit cost.
- Microhabitat provision consistently increases species richness and functional diversity across materials and exposure regimes.
- Water retention and surface texture (pits, grooves, pools) are key drivers; combining multiple features yields the strongest gains.

Case studies and further information can be found in the following directories:

- Marine Enhancement Directory (MEnD) A catalogue and map of all marine enhancement activities being undertaken in the UK from highest astronomical tide out to 200 nautical miles offshore. Adding to the database is free and should be promoted.

- OMRegdatabase Compiles completed coastal habitat creation schemes and adaptation projects including those outside the UK.

- Conservation Evidence Website summarises evidence from scientific literature on the effectiveness of conservation actions and is designed to support decision making about how to maintain and restore biodiversity, including actions to conserve biodiversity on marine artificial structures.

- The synopsis Enhancing the Biodiversity of Marine Artificial Structures was published in 2021. It covers published evidence of conservation interventions aimed at enhancing the biodiversity of marine artificial structures that are engineered to fulfil a primary function other than providing artificial habitats. It includes both intertidal and subtidal structures built or placed along coastlines (including in estuaries) and offshore, on the seabed and in the water column.

  43 conservation actions (22 intertidal and 21 subtidal) were identified for the Biodiversity of Marine Artificial Structures and 176 studies (118 intertidal and 58 subtidal) reporting their effects. However, it is important to be aware that the studies for this category are still in their early stages of development with only 1-5 studies linked for most of the actions, which compare with several dozen for some land-based enhancements. Further deployment and reporting of monitoring results is key to continue building on the evidence base and improve decision making in the future.

- Nature-based Solution Initiative. Founded in 2017 at the University of Oxford, the Nature-based Solutions Initiative is an international and interdisciplinary team of natural and social scientists, seeking to apply impactful research to shape policy and practice on nature-based solutions through research, teaching and engagement with policymakers and practitioners. The Initiative has created an evidence tool and compiled case studies which can be consulted for up-to-date scientific evidence and practice.

The synopsis Enhancing the Biodiversity of Marine Artificial Structures advises the following questions are asked when reviewing the applicability of the interventions outlined in various case studies/ synopsis to your situation:

- Do they deal with the same types of structures in the same environmental contexts?
- Do they report outcomes for the same types of target species/communities/habitats?
- Which studies are the most relevant?
- How dependent were the outcomes on local conditions?
- For how long and at what scale were the effects monitored?
- What comparators were used to measure effects?
- How strong is the evidence one way or another?
- What are the wider environmental risks and carbon footprint of implementing the interventions?

Apply the information to your situation and decide on the course of action most likely to deliver your desired outcomes. We suggest that you refer to the original source to gain a full understanding of specific studies.

5. Ecological coastal enhancement design

This chapter outlines the key steps in the design and monitoring of an ecological enhancement measure and outlines the consenting processes.

A stepped approach to assist with deciding which ecological intervention is selected is summarised below in Figure 21 and will be discussed in more detail in this Chapter.

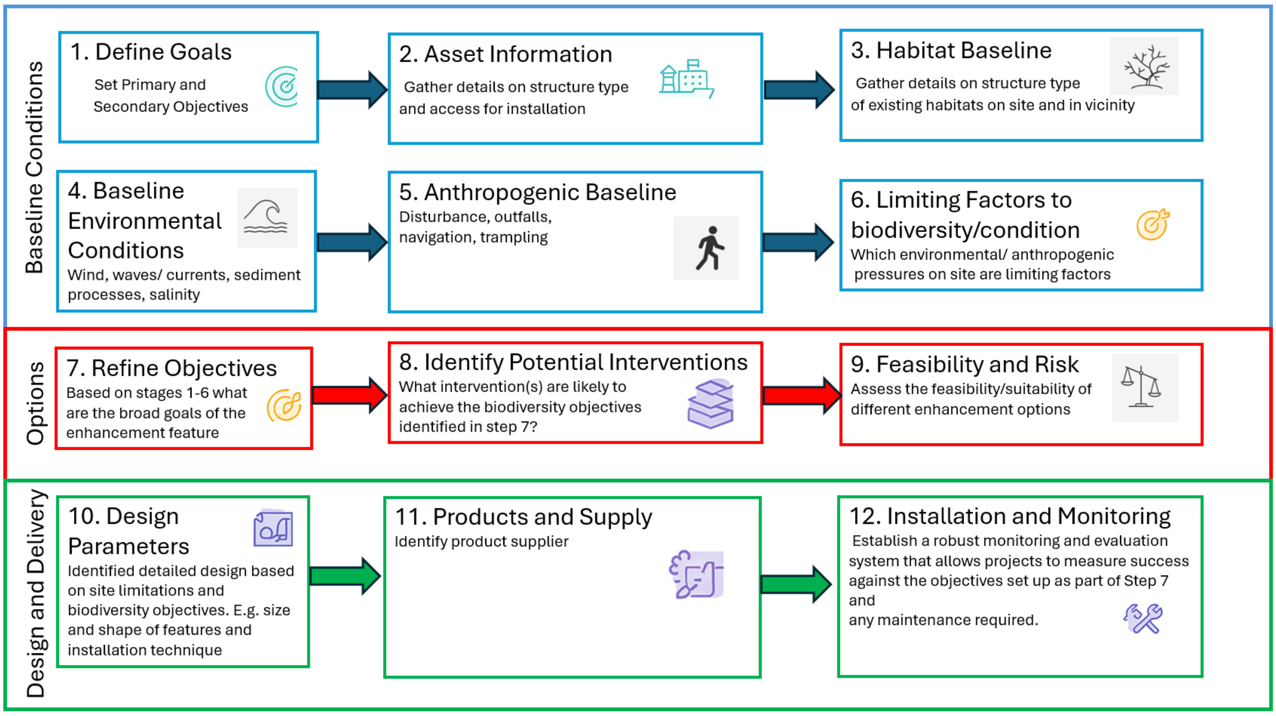


Figure 21 Stages of Ecological Enhancement Design

Every location is different – a bespoke solution for the structure and environmental context in question is required. Please refer to Chapter 3.3 on how the environmental context is likely to influence biodiversity outcomes.

Appendix 3 provides an assessment form template to inform project design and implementation.

5.1 Stepped approach

Step 1 - Define goals

Establish what the **goals of the intervention** are – both primary and secondary objectives should be clearly defined. Examples of categories and potential goals are presented below. The primary objective generally relates to the fundamental recovery of ecosystem health and integrity, for example ‘protect and enhance biodiversity by recovering native species and improving climate change resilience whilst not hindering the defence structure performance’. The secondary objectives are specific, measurable actions or outcomes that support the primary goals, for example ‘Enhance Connectivity- create ecological corridors between fragmented habitats to increase patch connectivity and allow species to move freely'. Table 1 highlights the range of factors which can be considered when setting project objectives.

Early engagement with stakeholders during the setting of goals and objectives can contribute to successful decision making. NRW has published [Principles supporting restoration and enhancement in a marine or coastal development proposal] to support developers in setting goals for their application for development consent or licence. The objectives should be Specific, Measurable, Achievable, Relevant and Time-bound (SMART) to guide the development and inform post-intervention evaluation.

Table 1 Considerations for setting project objectives

Ecology	**Environmental**	**Economic**	**Engineering**	**Social**	**Governance and policy**
Native species biodiversity Habitat complexity Invasive species management Support protected site objectives Promote specific target species Mimic natural rocky habitats/ biodiversity	Water quality Carbon sequestration Biofiltration Climate change resilience	Job creation Business opportunity Shore protection Insurability Licencing costs Costs of installation	Energy attenuation Shoreline stabilisation Structural integrity Upscaling of method	Aesthetics Tourism and recreation Education Health and Safety	Hazard Mitigation Political Obligations

Step 2 - Review asset information

Gain **information on the structure** on which the ecological enhancements are going to be implemented, for example:

- Is it a new build or an existing structure?
- What is the structure type?
- What is the material of the structure? What is the shape, inclination and extent of the structure?
- What is the maintenance regime of the structure?
- How difficult is access for implementation, monitoring and maintenance?

- What is the lifespan of the asset?

Step 3 - Observe baseline habitat

Observe the **existing habitats** on site and in the vicinity (refer to the Benthic habitat assessment guidance). Understanding the baseline habitat is key to identifying the appropriate target species and optimal ecological enhancement technique suitable for a specific location The route for new structures would differ to that for existing structures; for a new structure, observation would be done to similar structures in similar contexts.

- What is the habitat like? Subtidal or intertidal?
- How many microhabitats are present?
- What biodiversity is present?
- A benthic habitat assessment is recommended for each site to establish existing communities (constraints and opportunities), set realistic and measurable objectives and inform which ecological enhancement solution may be more effective in achieving the set objectives. Depending on the objectives, surveys may be needed of the existing structure to be eco-engineered or similar structures nearby if the project involves a new build, plus surveys of nearby natural reef habitats to identify the local species pool and nature of natural communities. For efficiency, this should be undertaken in parallel with an Extended Phase 1 Habitat Survey to confirm baseline biodiversity and likely presence / absence of protected and invasive species.
- Habitat connectivity of species
- What is the predation potential and foraging, predation and competition of species?
- Surrounding habitat.
- Distance to natural rocky habitat for source supply of species.

Step 4 - Review environmental baseline

Understanding the baseline environment is key to informing the potential success of the ecological enhancement technique for a specific location and informing a geomorphological/ hydrodynamic assessment.

Observe current **environmental conditions** including:

- Characteristics of the shore, whether it is rocky or mobile sediment, as this can determine how stable the created habitat is and what type of ecological enhancement may be appropriate.
- Wind exposure.
- Tidal range, elevations and sea level rise which can impact species/ habitat development.
- Wave and current exposure (and storms) – wave and current climate have influence on what species are likely to colonise but also there are interventions that may not resist wave / current actions.
- Sediment processes – interventions may be filled with sediments, or their functionality may be negatively impacted by abrasion. Furthermore, some species such as the honeycomb worm require an environment with sediment transport, namely sand, to feed its development.
- Water quality.
- Salinity.

- Turbidity levels.
- Water flow (currents), depth and quality.

Step 5 - Review anthropogenic baseline

Observe **other conditions of the site** that may influence the ecological enhancements.

- Exposure to anthropogenic disturbance such as trampling or light pollution
- Public access
- Navigation conditions and proximity to ports
- Proximity to outfalls and water intakes which could impact water quality/ flow
- Foraging
- Maintenance

If the site and the proposed location of the ecological enhancement is a public space, community engagement should be considered to raise awareness, gather support for the intervention and minimise the risk of vandalism.

Another aspect to be considered is whether the location is accessible for maintenance and monitoring because gathering evidence of the outcomes of interventions is key to build up knowledge and improve future decision making

Step 6 - Review limiting factors to biodiversity/condition

Establish **what is limiting the target biodiversity/condition**.

- What is the deficit between the target biodiversity/condition and the current condition?
- Is the target biodiversity/condition limited by intrinsic design features or extrinsic environmental parameters?
- What is limiting the target biodiversity/condition? Lack of shade, wind exposure, water retention, wave exposure, etc. For instance, some species targeted by the intervention may require shade, therefore can this factor be overcome or not. Would the provision of water retention features unlock biodiversity development?

Step 7 - Refine objectives

Refine the broad goals set as part of Step 1 by setting more **tangible objectives** based on steps 2-6, for example in terms of the extent of the intervention, type of habitat that is intended to be created and how existing limiting factors will be surpassed.

Example:

Step 1 – High level objective: promote colonisation of general sea life on a plain vertical seawall

Step 7 – Refined objective:

Promote colonisation of certain species of algae and limpets that thrive in intertidal environment with low wave exposure.

Create X no. of water retention features because in a location nearby it was successful and can be used as a control site.

Place new features at a certain level within the tidal range in an accessible location to allow for maintenance and monitoring.

Organise community engagement session to gather support and raise awareness.

Step 8 - Identify potential interventions

Make ecologically based decisions about what intervention(s) are most likely to deliver the biodiversity outcomes according to the objectives set up. Example of interventions are presented in Table 2.

The following may be considered:

- In the intertidal zone, interventions that provide moisture and shade have the greatest effect on the richness of sessile and mobile organisms, while water-retaining features had the greatest effect on the richness of fish (Strain et al., 2018).
- In the subtidal zone, small-scale depressions which provide refuge to new recruits from predators and other environmental stressors such as waves, had higher abundances of sessile organisms, while elevated structures had higher numbers and abundances of fish (Strain et al., 2018).
- The taxa that responded most positively to ecological enhancement in the intertidal were those whose body size most closely matched the dimensions of the resulting intervention (Strain et al., 2017).
- Different types of intervention are effective at enhancing different groups of organisms, ideally a range of approaches should be applied simultaneously to maximise niche diversity (Strain et al., 2017).

The Conservation Evidence Synopsis (2021) presents the summary of evidence of the effects of different interventions which could assist with this assessment (Table 2). Other key resources are the IGGI report (2017) and O'Shaughnessy et al. 2020 review. The ecological benefits of different type of interventions in accordance with the study undertaken by Strain et al. (2018) are presented in Table 3.

Table 2 Interventions - For a more exhaustive list of interventions and details refer to Conservation Evidence Synopsis by A.J Evans et al

Interventions
Use environmentally sensitive materials
Create rock pools (Retain water, depth >50mm)
Create groove habitats (Depressions with a length to width ratio > 3:1 and depth 1 50mm)
Create swim through habitats
Create protrusions (Protrusion with a length to width ratio ≤ 3:1)
Create flexible habitats (Materials such as rope, ribbon or twine)
Create ledges or ridges (Protrusion with a length to width ratio > 3:1)
Textured surfaces (Depressions and/or elevations ≤ 1mm)
Pit habitats (Depressions with a length to width ratio ≤ 3:1 and depth >50mm depth 1-50mm)

Interventions
Create hole habitats (Do not retain water, depressions with a length to width ratio ≤ 3:1 and depth>50mm)
Create crevice habitats (Depressions with a length to width ratio > 3:1 and depth >50mm)

*Table 3 Results of both intertidal interventions and subtidal interventions -Outcome of meta-analysis (underlined and in brackets) and qualitative reviews from Strain et al. (2018). Interventions are scored according to whether they had significant positive, negative or non-significant effects relative to controls or are not-applicable (n/a). Table extracted from Strain et al., (2018) and modified for the purpose of this note. *Tubeworms (e.g. Sabellaria alveolata) – interpolated assumptions replacing tropical features.*

Number of species

Microhabitat	Sessile	Mobile	Benthic	Fish
Texture	(non-significant)	n/a	n/a	n/a
Crevice	positive	non-significant	non-significant	n/a
Pit	n/a	n/a	positive	n/a
Rock pools	positive	non-significant	positive	(positive)

Abundance of species

Microhabitat	Sessile	Mobile	Benthic	Fish
Texture	positive	n/a	n/a	n/a
Crevice	positive	(positive)	non-significant	n/a
Pit	n/a	(positive)	non-significant	n/a
Rock pools	n/a	n/a	n/a	n/a

Number of species or abundance of habitat-forming taxa

Microhabitat	Sessile	Mobile	***Tubeworms****	Fish
Texture	positive	negative	positive	(non-significant)
Crevice	positive	positive	non-significant	non-significant
Pit	positive	(positive)	non-significant	non-significant
Rock pools	ns non-significant	non-significant	non-significant	positive

Notes:

- Texture – microscale manipulation applied to an entire intertidal or subtidal surface that produces depressions and raises of ≤ 1mm
- Crevice – intertidal or subtidal depressions with a length to width ratio > 3:1, and depth > 1mm
- Pit – intertidal or subtidal depressions with a length to width ratio < 3:1 and depth of > 1mm to 5cm. This may or may not hold water
- Intertidal water retaining structures – depressions or features including Vertipools and rockpools with a length to width ratio < 3:1 that hold water (≥ 5 cm depth) when the tide retreats
- Subtidal holes – subtidal depressions with length to width ratio < 3:1 and ≥ 5cm depth

Step 9 - Assess feasibility/suitability of different options

Assess the **feasibility/suitability** of different enhancement options. The assessment should include:

- Contribution to meeting primary and secondary goals.
- Whole life cycle cost.
  Carbon footprint lifecycle assessments. Heery E.C., et al. (2020) reveals the importance of considering carbon costs of enhancement actions, otherwise the net environmental effect of ecological enhancement may not be positive. Questions to ask include:
  -Does enhancement require additional concrete;
  -Can low-carbon concrete be used;
  -Can existing structures be retrofitted instead of replaced; and
  -What is embodied carbon per biodiversity gain?
- Asset management and maintenance requirements
  -Would maintenance affect the efficacy of the interventions?
  -Would colonisation by a protected species/habitat (e.g. *Sabellaria*) create issues for maintenance regimes?
  -Would attaching units/panels be a barrier to maintenance?
- Is a consent / licence / permit / environmental assessment required?
- Health and safety considerations.
- Risk of attracting non-native or invasive species.
  -Are there non-natives in the area?
  -Does the timing of intervention create new surfaces at a time when non-native larvae/propagules are in the water column ready to settle?
  -Does the intervention create shaded/downward-facing surfaces that are associated with non-indigenous species?

Dafforn K.A. (2017) provides examples to reduce opportunities for non-indigenous species establishment and spread. These include:

(1) manipulating the physical and chemical properties of structures to enhance native recruitment over NIS,

(2) enhancing resource use of structures by native species through “pre-seeding”,

(3) providing opportunities for native grazers and predators to easily access structures, and

(4) considering the timing of construction/maintenance/decommissioning for artificial structures such that resources are not made available when propagule pressure is also high’.

- Risk of displacing native species.
- Risk of changing current environmental conditions. Evaluate (in consultation with the engineering designer and contractor) durability, buildability and the engineering performance of the measures.
- Risk of affecting the integrity of the structure.
- Risk of the created habitats becoming ecological traps. See Komyakova et al. (2021) study.

- Risk of hindering future maintenance, repair and monitoring of the primary asset, as some options could hinder access or hide defects/early signs of a mode of failure (e.g. cracking).
- Evaluate other on-site specific challenges such as aesthetic considerations. Early stakeholders' consultation and engagement is key to map out what those challenges and opportunities.
- Do products/suppliers exist to deliver the intervention? Or can the interventions be installed without specialist services?

Step 10 - Identify detailed design parameters

- Decide the shape (e.g. optimum width: depth ratio to avoid creating traps)
- Decide the size

The optimum size will depend on the objective. A variety of sizes will maximise diversity. Match to body size of target species and life stages. Larger sizes are likely to be better for fish and larger invertebrates.

- Decide the material

Material choice is crucial alongside texture and microhabitat features; some coastal engineering materials (e.g. granite) may provide less habitat potential than more ecologically favourable materials (e.g. limestone) over the engineering design life. This is because of natural surface texture, chemical composition and the way these materials naturally weather and erode over time (Naylor et al., 2017).

- Decide the number – mimic local natural reefs, determined by cost, etc.

As part of Ecostructure project produced a range of outputs and tools to support decision making on how much of a specific habitat intervention would be needed to mimic natural habitats. This includes the BioPredict tool which estimates the biological communities likely to develop on proposed coastal structures and EF Predict which can be used to predict the ecosystem functions of biological communities supported by artificial structures, from which it's possible to infer the ecosystem services that they might provide.

- Decide how to distribute them - shore level, how much of the structure, etc. Lower shore may deliver higher diversity, dependent upon existing habitats impacted.
- Decide what installation technique is most suitable for your structure/budget.

Different installation techniques are presented in Table 4. The likely applicability of each installation technique for different assets is presented in Table 5.

Table 4 has been created with the aim to assist with the selection of the installation techniques based on general principles. However, as highlighted before, the final selection of the most appropriate installation technique requires a tailored assessment for the site / structure in hand.

Table 4: Installation techniques

Installation techniques
Drill-in (to create a depression by perforating/drilling from the surface)
Cast-in (to create a protrusion or depression when the material is still malleable, e.g. wet concrete).
Drop-in prefabricated units (to put into place prefabricated units to form part of the asset)

Installation techniques
Cut-in (to create a cavity from the surface)
Bolt-on (to attach to the asset using bolts or anchors)

Table 5: Techniques applicable to different assets.

Installation technique / type of asset	Drill-in	Cut-in	Cast-in	Bolt-on	Drop-in prefabricated units
Outfall	yes	yes	yes	yes	no
Open channel	yes	yes	yes	yes	no
Wall - includes concrete and masonry walls	yes	no	yes	yes	no
Embankment	-	-	-	-	-
Gabions	yes	no	no	yes	no
Rock armour and riprap	yes	no	no	yes	yes
Concrete faced	yes	no	yes	yes	yes
Ramps and slipways	yes	yes	yes	yes	no
Weir	yes	no	yes	yes	no
Steps	yes	yes	yes	yes	no
Groynes	-	-	-	-	-
Rock armour and riprap	yes	no	no	yes	yes
Concrete	yes	yes	yes	yes	yes
Bridge abutment	-	-	-	-	-
Piers and piles	yes	no	yes	yes	no
Scour protection – riprap	yes	no	no	yes	yes
Spillway	yes	no	yes	no	no

Step 11- Identify product supplier

Decide if any existing **products** suit the needs of the project (based on the chosen intervention(s) and most appropriate technique for the asset) or if non-specialist suppliers are more suitable.

Table 6 presents a list of currently available products from specialist suppliers, the intervention/s they deliver as well as their installation technique. Some of the products deliver more than one intervention at the same time.

The stock of products that NRW have available should be checked with All Wales Marine Advice Teams, email: marine.advice@cyfoethnaturiolcymru.gov.uk.

Table 6 Products from specialist suppliers. – This is a list of products that could be suitable for NRW assets. Other options/alternatives may be available

Installation technique	**Name of product**	**Description**	**Supplier**
Technique 6 – Bolt on precast vertical pools	Vertipools	Bolt on artificial rock pools	Artecology www.artecology.space
Technique 8 – Drop-in prefabricated units	BIOBLOCKs	Precast habitat enhancement unit	ARC marine Ltd (ARC marine's Reef Cube® system, used for artificial reefs and marine infrastructure protection) https://arcmarine.co.uk/
Technique 8 – Drop-in prefabricated units	EConcrete® rock pools	Creates rock pools and textured surfaces	ECOncrete https://econcretetech.com/
Technique 5 – Bolt-on precast panels and tiles	EConcrete® seawall panels	Creates rock pools, hole habitats and ledges or ridges	ECOncrete https://econcretetech.com/
Technique 4 – Cast-in textured, grooved and creviced concrete surfaces	ECOncrete® piles and jackets	Uses environmentally sensitive materials to create textured surfaces	ECOncrete https://econcretetech.com/
Technique 5 – Bolt-on precast panels and tiles	Living Seawall panels	Uses environmentally sensitive materials to create rock pools, hole habitats and crevice habitats	Inland and Coastal Marina Systems https://inlandandcoastal.com/product/living-seawalls/

Installation technique	Name of product	Description	Supplier
Technique 5 – Bolt-on precast panels and tiles	Sea-Hive	Uses environmentally sensitive Ultra High-Performance Concrete (UHPC) to create hole habitats, crevice habitats and textured surfaces	CubeX Industries Ltd http://www.cubexindustries.co.uk

One potential challenge in implementation and delivery arises from the reduced number of specialist suppliers together with their limited production capacity. This is especially relevant for certain ecological enhancement products such as Vertipools, rockpool units or BIOBLOCK units (see Section 5, Techniques 3 and 5). This can lead to long order books for those products requiring early procurement. Companies that have traditionally manufactured precast concrete products and have a strong supply chain and greater manufacturing capacity, are in a good procurement position to drive ecological enhancements involving textured concrete such as concrete panels, tiles, pile encasements, etc. (See Section 5, Techniques 4 and 6). It is expected that the outlook of procurement improves in the medium term as demand increases and suppliers proliferate and increase their production capacity.

Step 12- Establish monitoring and evaluation system

Installation and monitoring:

- Establish a robust monitoring and evaluation system that allows projects to measure success against the objectives set up as part of Step 7.
- Select the right time for the enhancements to be implemented - measures should be installed to coincide with native species settlement/recruitment windows to reduce risk of invasives (Naylor et al., 2017).

In general, the following principles should be considered when producing a monitoring strategy:

- Undertake a baseline survey. If the proposed works are aimed at enhancing a structure such that it attracts species present in the surrounding habitat, the baseline survey area should be close to the location of the ecological enhancement. If a new enhancement is considered with the aim of generating habitat/biodiversity which is not present in the area, further consideration is required regarding a suitable baseline (another similar site, literature review). NRW's Marine Ecology Datasets for Marine Developments and the National Biodiversity Network should be consulted to support decision making. NRW's dataset also includes Intertidal habitat survey map, Marine ecological assessments as part of the Water Framework Directive Monitoring Programme, Habitats Directive SAC maps, records of Invasive non-native species, etc.
- Frequency and timing of monitoring. The frequency and timing of monitoring will depend on the nature and site of the proposed ecological enhancements. Monitoring post deployment can be every 6 months, yearly, and after the initial years on a less frequent basis. Depending on the intervention, the species that are expected to colonise as well as site conditions, the monitoring frequency may need to be

adjusted. In any case, a consistent approach is required to account for seasonal variability and the ephemeral nature of biodiversity.

- Monitoring should encompass the ecological enhancement but the control site as well.
- Monitoring specifics should be in accordance with NRW Guidance available from: Natural Resources Wales / Benthic habitat assessments for marine developments, whenever applicable e.g. sabellaria monitoring, intertidal rocky shores and rock pools.

Success (or not) can be determined when comparing the survey results of the ecological enhancement with the baseline. General parameters which can be assessed:

- The extent of colonisation or percentage cover / patchiness if the ecological enhancement is a new structure with limited area
- Number of different species, as a measure of biodiversity.
- Abundance of each species.
- Presence of Invasive and Non-Native Species (INNS). A list of priority marine INNS is provided in https://gov.wales/invasive-aquatic-species-priority-marine-species. If INNS are identified, it should be reported to NRW.

Once the ecological enhancements are implemented, it is key to measure their success in achieving project goals and outcomes, hence the importance of setting measurable objectives. To measure success, a robust monitoring and evaluation system is required – see further information on monitoring in Section 8.3. Moreover, monitoring and evaluation for initial deployment of techniques will build the evidence-based on the implemented ecological techniques for a given range of settings which will inform the justification assessment at other schemes. The findings from the monitoring and evaluation could be published in the Conservation Evidence Journal so that they can be incorporated into the evidence base for future decision-making alongside NRW's own reporting and knowledge sharing channels. Further information regarding the Conservation Evidence is provided in Section 6.

A long-term viability concern related to implementation is the uncertainties around the future maintenance and management of ecological enhancements. As the evidence base builds up, there will be more data available to reduce uncertainties around maintenance and asset management.

Suggested minimum monitoring standard for coastal ecological enhancement projects

Minimum monitoring standard for Coastal Ecological Enhancement Projects

To support evidence-based decision making and improve consistency across projects, it is recommended that all ecological enhancement projects implement, as a minimum, the following monitoring programme, unless a risk-based justification applies.

Before installation

- Baseline ecological survey of the enhancement location.
- Baseline survey of a suitable control site (where practicable).
- Photographic record of the asset and surrounding habitat.

- Record of environmental conditions (tidal elevation, exposure, substrate, water quality where available).

Post-installation monitoring

Undertake monitoring at:

- 6 months (optional for rapid colonisation assessment)
- 12 months (minimum requirement)
- 24 months (recommended minimum project endpoint)
- Longer-term monitoring (3–5 years) where resources permit

Parameters to monitor

As appropriate to the enhancement type:

Ecological

- Species richness.
- Species abundance and/or percentage cover.
- Presence of habitat-forming species.
- Presence of Section 7 habitats or species.
- Presence of Invasive Non-Native Species (INNS).
- Evidence of ecological connectivity or utilisation by mobile fauna.

Physical condition

- Structural condition of enhancement features.
- Sediment accumulation or scour.
- Damage, dislodgement, wear or vandalism.
- Changes affecting functionality (e.g. loss of water retention capacity).

Asset management

- Implications for inspection and maintenance activities.
- Health and safety observations.
- Any operational issues arising from the enhancement.

Monitoring methods

Monitoring should normally include:

- Repeat fixed-point photography.
- Standardised quadrat surveys or biotope assessments.
- Comparison with baseline conditions.
- Comparison with a nearby control site where possible.

Reporting

Monitoring reports should:

- Evaluate success against project objectives.
- Document lessons learned.
- Record maintenance requirements.
- Record any INNS observations.
- Be shared through NRW, MEnD, scientific publications, or other knowledge-sharing platforms where appropriate.

Success criteria

Projects should define measurable success criteria before installation. Examples include:

- Increase in species richness relative to baseline.
- Colonisation by target species or habitat groups.
- Maintenance of feature functionality after 24 months.
- No significant increase in INNS presence.
- No adverse impact on asset performance or public safety.

Adaptive management

If monitoring demonstrates:

- Poor colonisation
- Excess sedimentation
- Excessive scour
- INNS colonisation

consider:

- Installing additional features
- Modifying designs

- Relocating features
- Biosecurity interventions

Other considerations

Although the ecological enhancement selection has been outlined as a linear 12-step approach, it should be noted that an iterative approach, going back to a previous step and changing the selected option, may be required to ensure that all the project requirements (cost, buildability, ecological benefits, environmental benefits, social benefits, etc.) have been considered and balanced appropriately.

Table 7 presents a qualitative comparison between different techniques that can be applied to two groups of structures: A) rock structures and B) vertical (or near vertical) concrete faced structures. Table 7 has been created with the aim to assist with the selection of the techniques based on general principles. However, as highlighted before, the final selection of the most appropriate technique requires a tailored assessment for the site / structure in hand. It is crucial that the knowledge and experience of local ecologists, oceanographers and experts is brought in to discuss the feasibility of options and to maximise the outcomes of the solutions. The information presented in this table is based on experience, the cases studies and literature review.

Further to Table 7, other combinations of installation techniques and interventions are possible. The following section includes a description of each technique together with key evidence-based information on cost, effectiveness, maintenance and asset management considerations, challenges and timescales are summarised below. This information is based on experience and the case studies and literature review presented in Appendix A and Section 9 of the note, respectively.

The Conservation Evidence Synopsis (2021), which presents the summary of evidence of the effects of different interventions, the IGGI report (2017) and O'Shaughnessy et al. 2020 review the latest research and further detail on the ecological enhancements covered in this note plus others not covered here.

Table 7: Cost value assessment for different techniques when used in rock structures (7a) and vertical concrete faced structures (7b). Relative comparison (very low / low / medium / high / very high) between four techniques identified as potential enhancement measures for rock/ vertical concrete faced structures. It is assumed that the techniques are applied in the same site and therefore environmental and anthropogenic exposure is the same, the existing habitats on the site are the same and the height with respect to the tide is the same

A) Rock structures	Capital cost	Ecological potential (1)	Asset management challenges	Additional benefits (2)
Drill-in pits and grooves	very low	low	very low	very low
Drill-in rock pools	low	medium	low	low
Drop-in precast enhancement units (with several habitat interventions)	very high	very high	medium	high

A) Rock structures	Capital cost	Ecological potential (1)	Asset management challenges	Additional benefits (2)
Bolt-on precast tiles and panels (with several habitat interventions)	medium	medium	medium	medium

B) Concrete vertical faced structures	Capital cost	Ecological potential (1)	Asset management challenges	Additional benefits (2)
Drill-in pits, grooves and crevices	very low	low	very low	very low
Bolt-on precast tiles and panels (with several habitat interventions)	very high	high	high	high
Bolt-on vertical pools	medium	high	very high	medium
Cast-in textured concrete	high	medium	medium	medium
Bolt-on green wall modules	low	medium	high	low

(1) Refers to ecological potential for species richness. The ecological benefits for each selected technique would need to be measured against the project-specific objectives
(2) In addition to ecological potential, including social benefits, wider environmental benefits and engineering benefits

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6. A guide to the regulatory process

This chapter details the environmental permits, licenses and consents that are likely to be required for coastal ecological enhancement projects in Wales. For any project early engagement with regulatory authorities is important. Regulators and advisors can identify the potential approvals that might need to be put in place before carrying out works. They can also help identify and advise on potential impacts at an early stage to enable project design to be optimised.

6.1 Consenting and licensing – all projects

Baseline data – prior to deployment of coastal ecological enhancement, an environmental desk study should be undertaken to identify the likely constraints and opportunities associated with the site and inform the likely consents, licences and permits that may be required. This desk study should inform a long list of enhancement opportunities, to be validated through site visit and field survey (Intertidal Biotope Survey) undertaken by an experienced marine ecologist. The long list can then be refined into a short-list of enhancement options based on more realistic and measurable objectives and clarify whether any additional field survey or further assessment is likely to be required.

Marine licensing – required for any licensable marine activity such as deposits or removals (using land or marine equipment) below Mean High Water Springs (MHWS) and in any tidal river to the extent of tidal influence require a marine licence from the NRW Marine Licensing Team (MLT). Coastal ecological enhancement deployment will typically require the submission of a marine licence application or will be integrated into new defence proposals as part of the main application. Minor works may only require a Band 1 (Low Risk) Marine Licence application, whilst typical activities will require a standard Band 2 application. Each application process requires specific supporting information filled in a specific form, requires payment of a fee and have determination periods of 3-6 weeks and 16 weeks respectively. The likely consenting route for selected ecological enhancement techniques is outlined in Section 8. It is advisable to engage with NRW MLT to confirm the likely application Band for the works via the following address: marinelicensing@cyfoethnaturiolcymru.gov.uk. Note that minor works such as coring / drilling holes in artificial structures may not require a marine licence, but liaison with NRW MLT is always recommended to confirm.

When developing enhancement proposals, either in isolation or as part of a project, consideration needs to be given to any consent determination periods (e.g. marine licensing Band 2 – 4 months), any baseline data collection and assessment required to support applications, and any site-specific mitigation measures that may be required to support deployment (seasonal restrictions, e.g. breeding / overwintering birds).

Water Framework Directive (WFD) Assessment – applications for a marine licence will need to be supported by a WFD Screening Assessment and / or a WFD Compliance Assessment. WFD requirements extend 1km offshore and involve consideration of water quality during construction and operation of assets and sensitivity of the existing environment. A WFD assessment may also be required to support a FRAP application. Proposals should aim to support delivery of any relevant WFD Mitigation Measures identified for affected waterbodies. In most instances, a WFD Screening should be

appropriate to enable the delivery of ecological enhancement structures. In more complex circumstances, a full WFD Compliance Assessment may be required.
Email wfdwales@cyfoethnaturiolcymru.gov.uk to request the NRW Guidance Note (GN78) on how to carry out a WFD assessment for a marine licence assessment.

6.2 Consenting and licensing – site-specific

Town and country planning – Requirements for planning permission extends to the Mean Low Water Springs (MLWS) mark requiring an application for planning permission prior to the delivery of certain proposals. Consultation with a Town and Country Planner is advised to identify whether any permitted development rights or exemptions apply to the proposals. Should planning permission be required, the overlap of consenting regimes in the intertidal zone may mean that both planning permission and a marine licence are required. The determination period for minor applications (<1 hectare) is eight weeks.

Habitats Regulations Assessment (HRA) – necessary where works are within or may affect the National Site Network (previously European Sites). HRA Stage 1: Screening is required to prove that proposals will not have a Likely Significant Effect (LSE) on the site. Where proposals are deemed to have an LSE (i.e. that mitigation is required to avoid LSE or any uncertainty remains in accordance with the 'precautionary principle'), a Stage 2: Appropriate Assessment (AA) is required to prove that the proposals will not have an Adverse Effect on Site Integrity (AEoSI). In the unlikely event or a confirmed or potential AEoSI, the Stage 3: Alternatives Assessment and Stage 4: Imperative Reasons of Overriding Public Interest (IROPI) tests may be required and Compensatory Measures secured. Most proposals will only require a Stage 1: Screening, and maybe a Stage 2: Appropriate Assessment should mitigation measures (timing / method of works, etc.) be required or the potential for an impact pathway remains uncertain. Where proposals are clearly not likely to lead to any impact pathway (spatial separation, terrestrial habitats lacking an impact pathway) an HRA may not be required, pending consultation with the relevant NRW Conservation Officer. Refer to NRW Habitats Regulations Assessment for your Environmental Permit for details.

Flood Risk Activity Permits (FRAPs) – The Environmental Permitting (England and Wales) Regulations 2016 require Flood Risk Activity Permit (FRAP) applications for proposed activities in, over, under or within 16m of a tidal main river as well as activities affecting sea defences (above the MHWS) and within 16 metres of the base of a sea defence. A FRAP may be required for proposed coastal ecological enhancement works depending on the type of activity proposed and its location. Certain activities may not need a bespoke FRAP but could fall under an Exemption or Exclusion. It is recommended that early engagement is undertaken with NRW Development and Flood Risk teams to discuss the proposal and establish whether any permitting requirements need to be met. Following the UKs departure from the EU on 31 January 2020 and the end of the transition period on 31 December 2020, the legal obligations relating to compliance with environmental permits and legislation will continue to apply. NRW will continue to issue and regulate all permits and licences in line with our current practice. Full details of the FRAP process are available on the NRW website Natural Resources Wales / Flood risk activity permits.

Land Drainage Consents - The Land Drainage Act 1991 requires the prior consent of the Internal Drainage District (IDD) for certain activities within their areas such as:

- Erecting, raising or altering any mill dam, weir or other obstruction to the flow of an ordinary watercourse
- Erecting a culvert
- Altering a culvert in a manner that would affect the flow.

Full details of the FRAP process are available on the NRW website Natural Resources Wales / Apply for land drainage consent.

Historic Environment – scheduled monuments, listed buildings or structures within conservation zone – appropriate consent would be required to make any change that may affect their special interest. Implementing coastal enhancements within structures that fall within those heritage protection categories may be challenging and the consenting process would need to be carefully considered in the timescales of the project. An Archaeological Desk-Based Assessment (DBA) and Heritage Impact Assessment may be required looking at the potential impact but also mitigation measures. Pending assessment, Scheduled Monument Consent or Listed Buildings Consent may be required. Early engagement with the relevant organisation is key to minimise programme and cost risks further down the line in the consenting process (for terrestrial and intertidal zones contact the relevant Welsh archaeological trust; Gwynedd, Clwyd-Powys, Dyfed, or Glamorgan Gwent, and for the marine zone the Royal Commission on Ancient and Historic Monuments of Wales). Advice can be given on the potential impact on the Historic Environment and the scope of any required archaeological works and necessary consents, including requirements to consult Cadw or other organisations.

The four regional Welsh archaeological trusts maintain the Historical Environment Records (HERs) on behalf of the Welsh Ministers. The Historic environment records provide detailed information about the historic environment of a given area. This includes Listed Buildings, Scheduled Monuments, Conservation Areas, Registered Parks and Gardens, Historic Landscapes, Conflict Sites, World Heritage Sites and Historic Placenames.

In accordance with the Historic Environment (Wales) Act 2016, the records are regularly updated, therefore consultation for every project should be considered. The public database on https://archwilio.org.uk/wp/ should be used for information only and at pre-desk study stage and should not be relied upon for decision making.

European Protected Species (EPS) licence – an ecological desk study (including Aderyn biodiversity records search) and ecological advice should be sought on the likely presence of EPS at the deployment site. EPS and their resting, sleeping and breeding sites are protected from damage and disturbance by law. A field survey may be required to confirm the likely presence / absence of such species. Species of higher prevalence for coastal deployments are otter and bats. Desk records should identify the presence of EPS flora such as Killarney fern. It is unlikely that marine EPS (cetaceans, seals and turtles) would be affected by coastal ecological enhancement as proposed herein but may need to be addressed via HRA where within or near SACs comprising marine EPS. Determination periods are 40 working days but will require sufficient data to support the application. Other nationally protected species may also be present, such as breeding birds, that may require licensing or targeted mitigation measures.

As described above, several legislative and policy drivers exist requiring the delivery of enhancements through project delivery by private and public organisations and in the general course of NRW duties. Delivery of ecological enhancement as coastal enhancement acts to support NRW goals to deliver Sustainable Management of Natural Resources, promote resilience of ecosystems and support well-being goals in line with the Environment (Wales) Act and Well-Being of Future Generations (Wales) Act.

7. Justification assessment: value analysis and outcomes

A decision to implement ecological enhancements will be made based on cost benefits, the level of risks and the ability to meet specific goals or outcomes. This section outlines some of the challenges and opportunities associated with the implementation decision.

One of the biggest challenges that public bodies and other parties involved in the management, design and construction of coastal and estuarine infrastructure face is how to assess the value for money of incorporating ecological enhancements so the assessment can inform a successful business case.

The cost side of the assessment can be relatively straight forward based on data available from other sites / projects where similar techniques have been applied. It is noted, however, that most of the work done to date implementing ecological enhancements are at prototype scale and pilot schemes or carried out by research projects using DIY methods which brings its own challenges (see Section 9). Some costs are likely to be much higher in practice (e.g. contractor time and overheads), whereas there would likely be economies of scale for manufacturing or installing large-scale projects, especially as suppliers become more commercialised and availability improves. Some indicative costs of ecological enhancement approaches are presented in Naylor et al. (2017) and O'Shaughnessy et al. (2020), including the likely economies of scale when interventions are scaled up from research or pilot projects to commercial practice (Naylor et al. 2017). Indicative costs for a selection of interventions were provided in Chapter 4.2 and Appendix 1.

A holistic approach to the identification and valuation of benefits is required so that a clear assessment of the importance of multiple benefits is undertaken.

Although a considerable amount of research has been conducted in the last decade to demonstrate the ecological benefits that enhancement techniques may have, it is very hard to predict how much biodiversity will be created and therefore, quantify the ecological benefits. This is particularly challenging when scaled up in implementations. Moreover, the ecological benefits are likely to be unique to the specific site where the enhancements are implemented (see section on Marine Biodiversity above). Factors such as type and diversity of the existing habitats, environmental exposure (e.g. wind, waves, water quality, etc.), anthropogenic exposure (e.g. trampling, harvesting, maintenance etc.), among others would likely influence the ecological benefits. Justifying the same benefits as other projects where the same technique has been applied would prove to be very difficult and potentially inaccurate. Research to predict ecosystem service flows that can help to support framing ecological benefits is currently underway.

A different way to look at the ecological benefits associated with the different ecological enhancement techniques would be to frame them as potential for habitat creation, as opposed to predict how much biodiversity is going to be created. Referring to potential rather than habitat creation as such brings the opportunity to draw on the outcomes and ecological benefits demonstrated by previous projects. With a similar objective, the ecological benefits could be framed as measurable conservation outcomes when compared to the equivalent artificial structure without ecological enhancements.

Wider environmental benefits are provided by coastal ecological enhancement including maintenance and delivery of ecosystem services (provisioning, regulating, supporting and cultural), supporting environmental targets and drivers (WFD mitigation measures, Environment (Wales) Act biodiversity duty to conserve and enhance, Well-Being Goals, etc.), climate change adaptation, educational opportunities and creation of habitat for other species.

Incorporating ecological enhancements to artificial structures can provide opportunities to enhance cultural services through acting as sites for tourism and recreation. Research by Fairchild, T at al. (2018) described the first direct experimental link between the functional emotion of interest and biodiversity that is likely to facilitate the flow of recreational and educational benefits from ecosystems. The study suggests that managing and enhancing artificial coastal habitats could increase public interest and consequently enhance educational, recreational and tourism value which strengths the case for managing coastal and estuarine structures to improve biodiversity. At the same time, increasing the interest of the public for features could be a means of getting support for and meeting planning conditions. Fairchild et al. (2018) notes that species richness is a key dimension of biodiversity driving human interest in ecosystems.

Ecological enhancements also present an aesthetic and amenity opportunity. Often, the public perceives the enhancements as visually appealing, and in some instances, they are perceived as an artistic piece and/or creating interest. Conversely, care should be taken so it does not look unkept and neglected, negatively impacting in the aesthetics value of the asset (Francis et al., 2015).

Encouraging colonisation can improve the resilience of the asset by limiting weathering, erosion and abrasion processes reducing the necessity of maintenance and frequency of repair, but conversely it may negatively affect the structural integrity (Coombes, M. et al., ,2013 and 2017). The positive and negative impacts of any ecological enhancements would be site specific and need to be carefully considered.

Limited work has been undertaken to date to demonstrate the benefits that ecological enhancements may have in reducing flood risks and wave overtopping because of increasing the roughness of the structure. There is currently a research gap in assessing the hydraulic performance of structures whose roughness has been increased by introducing ecological enhancements (Salauddin M. et al. ,2021).

However, Salauddin M. et al. ,2021 presents laboratory-based physical modelling investigations on the characteristics of wave overtopping on artificially roughened seawalls, concluding that "*reductions in dimensionless mean overtopping rate (by up to 100% in comparison to the plain seawall reference condition) were limited to impulsive (violent) wave conditions, with no significant differences (for all tested roughness configurations) in mean overtopping rates being observed for non-impulsive wave conditions compared to the plain vertical seawall (reference condition)*". The findings are very relevant given that the wave impact hazards associated to impulsive wave conditions are generally higher than for non-impulsive wave conditions.

The results suggest that the addition of ecological enhancement interventions to seawalls that increase their roughness, could provide benefits in reducing wave energy, mitigating wave overtopping and reducing flood risks behind sea defences. However, it is important to note that the study was not scaled to reflect real-life tried-and-tested ecological enhancement designs in size, flexibility or density, so cannot directly predict the likely effects in practice. Nevertheless, the work provides proof-of-concept that increasing surface roughness may offer reductions in wave overtopping. The challenge remains of quantifying those benefits as current design guidance to predict hydraulic performance of the vertical wall only exist for plain vertical walls.

Another challenge related to the justification assessment is the difficulty to demonstrate the long-term viability of ecological enhancements. Several trials have been conducted over short timeframes, and it is too soon to know how long various techniques will withstand exposure to the marine environment in different contexts. Questions such as whether the ecosystem will be sustained under a changing climate arise – will the habitat be there in 20 years' time?

In any case, it is a good opportunity for NRW and other organisations to demonstrate best practice in providing enhancements and increasing resilience and ecosystem function on the Welsh coast.

8. Communication, engagement and public safety

Stakeholder engagement can be a useful tool to aid project design and identifying resource for project implementation and understanding the full benefits of a project beyond ecological enhancement. Engagement can be a time-consuming activity and require additional funding, so it is important to identify its purpose.

Effective engagement can contribute to the following:

Informed decision making- e.g. local community knowledge of a coastline can ground truth the potential success of ecological enhancement projects.

Building resilience- e.g. Early engagement builds trust community buy in to biological enhancement projects.

Policy funding and support- e.g. Demonstrating strong community engagement is often required to secure and identify funding opportunities. Funding for projects can come from a variety of sources including private funding and research grants.

Ensuring long term success- Co-designed projects are more likely to be supported and maintained by local communities and promote uptake by others. Linking monitoring needs with academic institutions can ensure that monitoring is undertaken by skilled individuals and lessons learnt are shared more widely.

Key stakeholders of ecological enhancement projects should be identified at an early stage, they can include coastal asset owners, national and local government, schools, communities and interest groups. Stakeholder mapping is a useful tool in identifying and analysing the individuals or groups that can influence project design or are affected by a project. A useful guide to stakeholder mapping can be found here: https://www.communications.gov.uk/publications/ensuring-effective-stakeholder-engagement/. The role of each stakeholder and the aspects of project that they would be interested in can help identify the most appropriate form of communication.

Several techniques can be used for engagement purposes including interviews, workshops, focus groups, meetings, surveys and online tools. As part of the Ecostructure Project Callaway (2022) produced a guide to integrating stakeholder interests into eco-engineering projects, this reflects the outcomes of several trial engagement forms and a summary of recommendations.

Case Study: public engagement and vertipools North Edinburgh, Scotland (https://edinburghlivinglandscape.org.uk/project/grey-to-green/)

A collaborative public engagement project was set up involving the Scottish Wildlife Trust, Glasgow University, ESALA, Artecology, and Concrete in the Classroom. It worked with local schools to teach coastal wildlife and processes, blending art, ecology, engineering, and bio-geomorphology. Students designed and attached concrete structures to coastal defences to enhance biodiversity.

Two artificial "vertipools" by Artecology were installed on sea defences to create marine habitats in the otherwise hostile intertidal zone disrupted by vertical structures. These pools aimed to support species such as seaweeds, barnacles, and lichens.

The project also trained early-career researchers in public engagement and hosted a workshop with Edinburgh Adapts for researchers, policymakers, and practitioners on coastal change and its benefits for people and wildlife.

Installed structures at Cramond will be monitored by Glasgow University students and RBGE researchers, with residents encouraged to observe species colonization.

Figure 22 North Edinburgh school pupils learning on the beach and Artecology Vertipool Source: Artecology

Case Study: Artecology engagement

Artecology undertake a variety of engagement events merging creative practice with environmental stewardship, fostering community connection to nature through workshops, performances, and exhibitions. Key initiatives include collaborative research projects designed to promote sustainability and ecological awareness; using workshops to teach participants about biodiversity and ecological enhancement and using a Co-Create approach where people get hands-on experience of creating Vertipools. These events often feature interdisciplinary approaches, uniting artists, scientists, and local communities.


A B


C D

Figure 23 Artecology Engagement events

A) Young people from Middlesborough taking part in a Co-Create activity;

B) Children making Artecology CoCreate artefacts at Shoreham Port as part of the Southwick Reef project;

C) University of Bournemouth discovering Vertipools;

D) Nigel George (Artecology lead) talking to young people from Portsmouth about ecological enhancements. Source: Artecology

Potential risks to public safety also need to be considered for ecological enhancement projects, in line with the Construction (Design and Management) Regulations 2015.

As identified by Roco et al (2025) the main risks related to these types of projects are:

- Slipping whilst walking on unstable surfaces or falling when trying to climb structures as public try to access features such as textured seawall panels
- Getting trapped, e.g. swimmers getting stuck in underwater installations or structures collapsing on top of individuals
- Navigational safety risks, e.g. small recreational vessels being damaged by underwater installations.

These risks can be managed through project design such as installing fences to limit public access if necessary; making holes in structures too small for people to climb on and alerting the public to the risks through the use of signs and public engagement.

9. Recommendations

This guidance has highlighted that there are further opportunities for ecologically enhancing hard infrastructure in Wales both in terms of retrofitting existing infrastructure and incorporating it into the design of new infrastructure. Case studies were presented to show that there are a range of option available and existing technical ability to enable this. The step-by-step guide in this guidance aims to help future projects through the design stages to encourage further uptake.

There are also a range of actions which could result in greater uptake and greater benefits for biodiversity.

Strategic

There are multiple opportunities to strengthen the delivery, regulation, and uptake of marine and intertidal environmental enhancements. These include increasing funding for implementation and monitoring, streamlining licensing processes, and exploring legislative flexibility to support innovation. Organisations could further invest in developing specialist skills, expand ecological expertise through training and collaboration, and grow the pool of qualified personnel to build long-term resilience.

Better communication—both internally and with the public—can improve understanding of how flood risk management and environmental enhancements complement one another. Enhancing data availability, clarifying regulatory responsibilities, and establishing shared industry targets would support more confident, consistent, and aligned project planning. Knowledge sharing on design, structural integrity, costs, maintenance, and habitat suitability would help inform decision making, while connecting academic research with large-scale delivery can boost practical impact.

Finally, showcasing successful projects, appointing organisational champions, hosting technical surgeries, and creating a more formalised approach for integrating enhancements into maintenance planning would all help embed best practice and increase support and uptake across the sector.

Project level

There is strong potential to improve the delivery, monitoring, and long-term success of ecological enhancements on coastal and marine infrastructure. Establishing dedicated teams, budgets, and processes for monitoring, maintenance, and community engagement would significantly strengthen capacity and project outcomes. Early engagement with stakeholders—including communities, specialists, and regulators—can improve design quality, unlock additional funding opportunities, and reduce risks or opposition.

Embedding ecological enhancements into business cases, capital project processes, routine maintenance cycles, and funding applications can help mainstream these approaches. This includes recognising the need for both material and ecological specialists throughout design and delivery. Collaboration with universities, volunteers, and suppliers can expand monitoring capability, while training tools, guidance, and structured knowledge-sharing (e.g., lessons learned documents, interpretation boards) can build wider organisational understanding.

Linking academic research with practical implementation, retrofitting enhancements to existing assets, and streamlining processes from concept to deployment all offer opportunities to increase efficiency, maximise value, and support more consistent, informed decision making across the sector.

References

1. Aguilera M.A., Broitman B.R. & Thiel M. (2014) Spatial variability in community composition on a granite breakwater versus natural rocky shores: lack of microhabitats suppresses intertidal biodiversity. Marine Pollution Bulletin, 87, 257–268.

2. Armstrong, S., West, V.A., Hull, S., and Scott, C.R. 2019. Supporting the implementation of the Welsh National Marine Plan: Enhancing marine ecosystems. 106 pp, NRW, Bangor.

3. Artecology. Available: http://www.artecology.space [Accessed 30 July 2021].

4. Borsje, B.W., Van Wesenbeeck, B.K., Dekker, F., Paalvast, P., Bouma, T.J., Van Katwijk, M.M. & De Vries, M.B. (2011). How ecological engineering can serve in coastal protection. Ecological Engineering, 37, 113-122. 10.1016/j.ecoleng.2010.11.027

5. Callaway, R (2022) Integrating stakeholder interests into eco-engineering projects- Guidance and case studies. Ecostructure Project, Swansea University, Biosciences.

6. Chapman M.G. & Underwood A.J. (2007) Maintenance of chitons on seawalls using crevices on sandstone blocks as habitat in Sydney Harbour, Australia. Journal of Experimental Marine Biology and Ecology, 347, 134–143.

7. Chee, S., Wee, J., Wong, C., Yee, J., Yusup, Y. and Mujahid, A., (2020). Drill-Cored Artificial Rock Pools Can Promote Biodiversity and Enhance Community Structure on Coastal Rock Revetments at Reclaimed Coastlines of Penang, Malaysia. Tropical Conservation Science, 13, p.194008292095191.

8. Coombes, M., Naylor, L., Viles, H. and Thompson, R., (2013). Bioprotection and disturbance: Seaweed, microclimatic stability and conditions for mechanical weathering in the intertidal zone. Geomorphology, 202, pp.4-14.

9. Coombes, M., Viles, H., Naylor, L. and La Marca, E., (2017). Cool barnacles: Do common biogenic structures enhance or retard rates of deterioration of intertidal rocks and concrete? Science of The Total Environment, 580, pp.1034-1045.

10. Cordell, J.R., Toft, J.D., Munsch, S. & Goff, M. (2017). Benches, beaches, and bumps: how habitat monitoring and experimental science can inform urban seawall design, Boca Raton, Florida, CRC Press.

11. Dafforn K.A. (2017) Eco-engineering and management strategies for marine infrastructures to reduce establishment and dispersal of non-indigenous species. Management of Biological Invasions, 8, 153–161.

12. Department of Environment Flood and Rural Affairs (Defra) (2006), Shoreline management plan guidance Volume 1: aims and requirements.

13. Duarte, C. M. et al. 2020. Rebuilding marine life. — Nature 580: 39-51. 10.1038/s41586-020-2146-7

14. Econcrete Inc. 2019. Available: http://www.econcretetech.com/ [Accessed 30 July 2021].

15. Evans, A.J., Firth, L.B., Hawkins, S.J., Morris, E.S., Goudge, H. & Moore, P.J. (2016). Drill-cored rock pools: an effective method of ecological enhancement on artificial structures. Marine and Freshwater Research, 67, 123-130. 10.1071/MF14244

16. Evans, A., Garrod, B., Firth, L., Hawkins, S., Morris-Webb, E., Goudge, H. and Moore, P., 2017. Stakeholder priorities for multi-functional coastal defence developments and steps to effective implementation. Marine Policy, 75, pp.143-155.

17. Fairchild, T., Fowler, M., Pahl, S. & Griffin, J. (2018). Multiple dimensions of biodiversity drive human interest in tide pool communities. Scientific Reports, 8(1)

18. Ferrario, F., Iveša, L., Jaklin, A., Perkol-Finkel, S. & Airoldi, L. (2016). The overlooked role of biotic factors in controlling the ecological performance of artificial marine habitats. Journal of Applied Ecology, 53, 16-24. 10.1111/1365-2664.12533

19. Firth, L.B., Browne, K.A., Knights, A.M., Hawkins, S.J. & Nash, R. (2016). Eco-engineered rock pools: a concrete solution to biodiversity loss and urban sprawl in the marine environment. Environ Res Lett, 11, 094015. 10.1088/1748-9326/11/9/094015

20. Firth, L.B., Thompson, R.C., Bohn, K., Abbiati, M., Airoldi, L., Bouma, T.J., Bozzeda, F., Ceccherelli, V.U., Colangelo, M.A., Evans, A., Ferrario, F., Hanley, M.E., Hinz, H., Hoggart, S.P.G., Jackson, J.E., Moore, P.J., Morgan, E.H., Perkol-Finkel, S., Skov, M.W., Strain, E.M., Belzen, J.V. & Hawkins, S.J. (2014). Between a rock and a hard place: environmental and engineering considerations when designing coastal defence structures. Coastal Engineering, 87, 122-135. 10.1016/j.coastaleng.2013.10.015

21. Francis, R.A., Richardson, V., Cockel, C. & Hoggart, S. (2015). Living Flood Defence Walls: Reconciliation Ecology in an Urban Estuary. 10.13140/RG.2.1.2817.4807

22. Francis, R.A., Hoggart, S.P., Gurnell, A.M. & Coode, C. (2008). Meeting the challenges of urban river habitat restoration: developing a methodology for the River Thames through central London. Area, 40, 435-445.

23. Gowell, M., Coombes, M. and Viles, H., (2015). Rock-protecting seaweed? Experimental evidence of bioprotection in the intertidal zone. Earth Surface Processes and Landforms, 40(10), pp.1364-1370.

24. Hall A.E., Herbert R.J.H., Britton J.R. & Hull S.L. (2018) Ecological enhancement techniques to improve habitat heterogeneity on coastal defence structures. Estuarine, Coastal and Shelf Science, 210, 68–78.

25. Hall, A.E., Herbert, R.J.H., Britton, R.J., Boyd, I. & George, N. (2019). Shelving the Coast with Vertipools: Retrofitting Artificial Rock Pools on Coastal Structures as

Mitigation for Coastal Squeeze. Frontiers in Marine Science, 6, 456. 10.3389/fmars.2019.00456

26. Hancock, M. (2000). Artificial floating islands for nesting Black-throated Divers Gavia arctica in Scotland: construction, use and effect on breeding success. Bird Study, 47, 165-175. 10.1080/00063650009461172

27. Heery E.C., Lian K.Y., Loke L.H.L., Tan H.T.W. & Todd P.A. (2020) Evaluating seaweed farming as an eco-engineering strategy for 'blue' shoreline infrastructure. Ecological Engineering, 152, 105857.

28. Historic Environment Group, Climate Change Subgroup (2020), Historic Environment and Climate Change in Wales. Sector Adaptation Plan

29. Jackson, J.E. (2015). The influence of engineering design considerations on species recruitment and succession on coastal defence structures. Plymouth University.

30. Komyakova V., et al. (2021). A multi-species assessment of artificial reefs as ecological traps. Ecological Enfineering, 171, 106394.

31. Lawrence P.J et al. (2021). Artificial shorelines lack natural structural complexity across scales. Proc. R. Soc. B 288:20210329.

32. Liversage, K., Cole, V., Coleman, R. & Mcquaid, C. (2017). Availability of microhabitats explains a widespread pattern and informs theory on ecological engineering of boulder reefs. Journal of Experimental Marine Biology and Ecology, 489, 36-42. 10.1016/j.jembe.2017.01.013

33. Macarthur, M., Naylor, L. A., Hansom, J. D., & Burrows, M. T. (2020). Ecological enhancement of coastal engineering structures: Passive enhancement techniques. Science of the Total Environment, 740, [139981]. https://doi.org/10.1016/j.scitotenv.2020.139981

34. Mant, R., Perry, E., Heath, M., Munroe, R., Väänänen, E., Großheim, C., Kümper-Schlake, L. (2014) Addressing climate change – why biodiversity matters. UNEP-WCMC, Cambridge, UK.

35. Metcalfe, D (2015). Multispecies Design. PhD thesis, University of the Arts London and Falmouth University.

36. Moreira J., Chapman M.G. & Underwood A.J. (2007) Maintenance of chitons on seawalls using crevices on sandstone blocks as habitat in Sydney Harbour, Australia. Journal of Experimental Marine Biology and Ecology, 347, 134–143.

37. Morris, R.L., Heery, E.C., Loke, L.H.L., Lau, E., Strain, E.M.A., Airoldi, L., Alexander, K.A., Bishop, M.J., Coleman, R.A., Cordell, J.R., Dong, Y.-W., Firth, L.B., Hawkins, S.J., Heath, T., Kokora, M., Lee, S.Y., Miller, J.K., Perkol-Finkel, S., Rella, A., Steinberg, P.D., Takeuchi, I., Thompson, R.C., Todd, P., Toft, J.D.T. & Leung, K.M.Y. (2019). Design options, implementation issues and evaluating success of ecologically engineered shorelines. Oceanography and Marine Biology: an Annual Review.

38. Moschella, P.S., Abbiati, M., Åberg, P., Airoldi, L., Anderson, J.M., Bacchiocchi, F., Bulleri, F., Dinesen, G.E., Frost, M. & Gacia, E. (2005). Low-crested coastal defence structures as artificial habitats for marine life: using ecological criteria in design. Coastal Engineering, 52, 1053-1071. 10.1016/j.coastaleng.2005.09.014

39. Naylor L.A., Kippen H., Coombes M.A., Horton B., MacArthur M. & Jackson N. (2017) Greening the Grey: A Framework for Integrated Green Grey Infrastructure (IGGI). Technical Report. University of Glasgow, Glasgow. Accessible at: http://eprints.gla.ac.uk/150672/.

40. Ng, C.S.L., Lim, S.C., Ong, J.Y., Teo, L.M.S., Chou, L.M., Chua, K.E. & Tan, K.S. (2015). Enhancing the biodiversity of coastal defence structures: transplantation of nursery-reared reef biota onto intertidal seawalls. Ecological Engineering, 82, 480-486. 10.1016/j.ecoleng.2015.05.016

41. O'Shaughnessy K.A., Hawkins S.J., Evans A.J., Hanley M.E., Lunt P., Thompson R.C., Francis R.A., Hoggart S.P.G., Moore P.J., Iglesias G., Simmonds D., Ducker J. & Firth L.B. (2020) Design catalogue for eco-engineering of coastal artificial structures: a multifunctional approach for stakeholders and end-users. Urban Ecosystems, 23, 431–443.

42. Paalvast, P., Van Wesenbeeck, B.K., Van Der Velde, G. & De Vries, M.B. (2012). Pole and pontoon hulas: an effective way of ecological engineering to increase productivity and biodiversity in the hard-substrate environment of the port of Rotterdam. Ecological Engineering, 44, 199-209. 10.1016/j.ecoleng.2012.04.002

43. Perkol-Finkel, S. & Sella, I. (2015). Harnessing urban coastal infrastructure for ecological enhancement. Proceedings of the Institution of Civil Engineers-Maritime Engineering. Thomas Telford Ltd.

44. Perkol-Finkel, S., Ferrario, F., Nicotera, V. & Airoldi, L. (2012). Conservation challenges in urban seascapes: promoting the growth of threatened species on coastal infrastructures. J. Appl. Ecol., 49, 1457-1466. 10.1111/j.1365-2664.2012.02204.x

45. Pioch, S., Relini, G., Souche, J., Stive, M., De Monbrison, D., Nassif, S., Simard, F., Allemand, D., Saussol, P., Spieler, R. and Kilfoyle, K., 2018. Enhancing eco-engineering of coastal infrastructure with eco-design: Moving from mitigation to integration. Ecological Engineering, 120, pp.574-584.

46. Pister, B. (2009). Urban marine ecology in southern California: the ability of riprap structures to serve as rocky intertidal habitat. Marine Biology, 156, 861-873. 10.1007/s00227-009-1130-4

47. Roca, M., Heredge, J, Procenca, B., Rato, L.D., De Sutter, R, Hick, E., Flikweert, J. Challinor, S., Naylor, L.A., Matthewson, T. (2025) Greening coastal infrastructure through eco-engineering, C820), CIRIA, London, UK

48. Salauddin M, O'Sullivan JJ, Abolfathi S and Pearson JM (2021) Eco-Engineering of Seawalls—An Opportunity for Enhanced Climate Resilience from Increased Topographic Complexity. Front. Mar. Sci. 8:674630. doi: 10.3389/fmars.2021.674630

49. Strain, E., Olabarria, C., Mayer-Pinto, M., Cumbo, V., Morris, R., Bugnot, A., Dafforn, K., Heery, E., Firth, L., Brooks, P. and Bishop, M., 2018. Eco-engineering urban infrastructure for marine and coastal biodiversity: Which interventions have the greatest ecological benefit? Journal of Applied Ecology, 55(1), pp.426-441.

50. Witt, M., Sheehan, E., Bearhop, S., Broderick, A., Conley, D., Cotterell, S., Crow, E., Grecian, W., Halsband, C. & Hodgson, D. (2012). Assessing wave energy effects on biodiversity: the Wave Hub experience. Philosophical Transactions of the Royal Society A, 370, 502-529. 10.1098/rsta.2011.0265

51. Yellin, J.M. (2014). Evaluating the efficacy of an artificial floating island as fish habitat in the Chicago River: A pilot study. Thesis. University of Illinois at Urbana-Champaign. 42pp.

Appendix 1 Case studies

Technique 1 — Drill-in pits, grooves and crevices

Case 1: Plymouth Breakwater, England (Firth et al., 2014 and Jackson, J. 2015)

Intervention and design

Plymouth Breakwater is a detached breakwater 1.56km in length made of limestone with some granite paving. The structure lies ca. 3 m above chart datum and extends to ca. 10 m into the subtidal. The feature is protected on the seaward side by the addition of cast concrete wave breaker armour units; these are rectangular frustums measuring 6.85 m× 3.20 m at the base and 2.35 m high.

During the casting of the wave-breaker units, surface complexity was added by drilling pits (14 mm and 22 mm diameter) to a depth of 25 mm. Each pit had a slight angle so that water was retained. Pits were drilled within a 100 cm × 100 cm area, within each area a total of 100 pits were drilled, each separated by 10 cm. In total eight sets of 14 mm and eight sets of 22 mm pits were drilled. 8 control quadrats of 100 × 100 cm with no pits were also monitored.

Monitoring

All colonising animals and algae within each quadrat (100 × 100 cm) were identified and counted two years after the deployment of the blocks. Data were analysed using a non-parametric Kruskal–Wallis test. Multiple Mann–Whitney U tests were used to conduct post hoc comparisons using a Bonferroni adjusted p-value for multiple comparisons of 0.05/3=0.016

Outcomes

A total of 33 species were observed in the treatments on Plymouth Breakwater (functional groups included algae, anemones, hydroids, ascidians, bryozoans, annelids, bivalves, sponges, gastropods and barnacles).

Six of the 10 functional groups were unique to the drilled pits (anemones, annelids, ascidians, bivalves, hydroids and sponges). Undertaken tests revealed that both the 14 mm and 22mm pits had significantly greater species richness compared to the control plots while there was no difference between the two treatments.

Results showed clear zonation patterns across tidal heights:

- upper zones → more stress-tolerant species
- lower zones → higher diversity and abundance

The orientation and wave exposure further influenced species composition.

Engineering and regulatory notes

This case study shows that relatively simple interventions such as drilling holes into concrete armour units can significantly enhance local biodiversity. These modifications increase surface complexity and provide refuges from desiccation and predation, improving recruitment and survival. Importantly, such ecological enhancement measures can be implemented without compromising structural integrity or primary coastal defence function.

Case 2: Runswick Bay, North Yorkshire & Boscombe, Poole Bay, UK (Naylor et al., 2017; Hall et al., 2018)

Intervention and design

Runswick Bay
The Runswick Bay project (North Yorkshire, UK) is an award-winning ecological enhancement coastal defence scheme that integrates flood protection with biodiversity enhancement in a sensitive Marine Conservation Zone. Runswick Bay is a Marine Conservation Zone (MCZ) designated for its intertidal habitat.

The key innovation was modifying the rock armour to increase surface complexity and habitat availability:

- Drilled holes and grooves in granite rock armour to retain water and provide refuges
- Artificial rock pools cut into boulders (≈70 pools installed)
- “Distressed” and irregular boulder surfaces to mimic natural rock
- Placement of seed/natural boulders to encourage rapid colonisation

These features increased:

- water retention at low tide
- microhabitat diversity
- refuge from desiccation and predation

Boscombe, Poole Bay
Arrays of holes and grooves were created in limestone rock groynes in southern England. Boscombe is near a Special Area of Conservation (SAC)

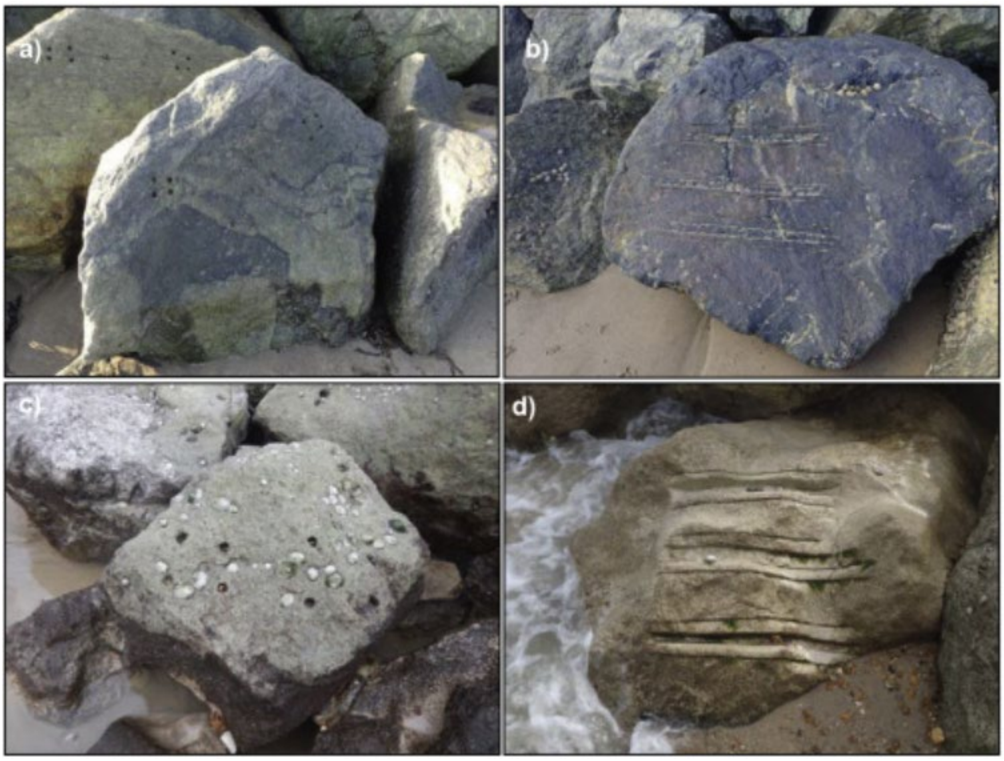


Figure 24 Positioning of a) Holes at Runswick Bay, b) Grooves at Runswick Bay, c) Holes at Boscombe, d) Grooves at Boscombe. (Source: Hall et. al, 2018)

Monitoring

Pits and groves habitat features were tested at Runswick Bay (Granite) and Boscombe (Limestone). The aim was to test the efficacy of increased surface heterogeneity and retrofitted water retaining features in improving ecosystem enhancements of rock armour. Biodiversity on both sites was monitored for 12 months.

Outcomes

- Limestone had higher overall species richness and diversity than the granite rock armour.
- For both rock types (granite and limestone), there was a significant increase in species richness and species diversity in the holes and grooved treatments compared to the business-as-usual unenhanced control.
- The increase in species diversity was greatest in the grooved treatments. Species of commercial importance (e.g. crabs) were only found in the enhanced areas.

Cost and buildability

- The cost of retrofitting holes into rock armour varied by material type.
- Limestone was less expensive to retrofit (£10/m^3 or 4 hours for 48 boulders) than granite (£55/m^3 or 2 hours to retrofit 12 boulders). This equates to ~£17/m^3 and £88/m3 in additional costs to add the enhancements onto limestone and granite, respectively.
- Standard rock armour for revetments costs between £42 – 107/m^3.

- Adding drill holes to the granite rock armour would be approximately 1.2 to 2 times the business-as-usual costs for commercial rock armour. This means it would cost between £130 -£195/m^3 for combined rock purchase and drilling costs.
- For limestone these costs would be lower, adding between 15-40% to the cost of business-as-usual rock armour, thus costing between £84-£150/m^3.

Engineering and regulatory notes

- The habitat creation assisted approval of the Runswick Bay coastal defence scheme by the Marine Management Organisation and Natural England, as it is within a Marine Conservation Zone.
- The size and density of the holes were too small to adversely impact on the engineering performance of rock armour.

Techniques 2 and 3 - Cut-in and cast-in rockpools

Case 3: Penrhyn Bay, Wales (Firth et al., 2014)

Intervention and design

During construction of coastal defence structures, cores are often drilled in boulders to test their density. These boulders are then placed within the structure to function as normal. When these boulders are placed with the cores running vertically, they can be infilled with concrete to retain water and thus function as artificial rock pools. In June 2012, nine cores were found and in-filled with concrete to a depth of 10 cm on the eastern breakwater at Penrhyn Bay.

Monitoring

This was a nine-month demonstrator project (Jun 2012–Mar 2013). In March 2013 pools and adjacent emergent substrata of comparable area were visually inspected and all epibiota identified.

Outcomes

- Only five cores retained water sufficiently to function as pools.
- A total of eight species colonised the boulders (pools and emergent rock) throughout the experiment.
- Pools supported significantly greater species richness (including barnacles, shrimp, gastropods, and algae) than emergent substrata (barnacles and gastropods only). Coralline algal germlings and shrimp were found in the artificial pools.

Key lessons

- It must be noted that this was a demonstration project and that a fully replicated long-term experiment is essential to accurately assess patterns of distribution and abundance in relation to the different habitat types.

Technique 4 – Cast-in textured, grooved and creviced concrete surfaces

Case 4: Eco-enhanced stormwater outfall, Hannafore Beach, Cornwall (Naylor et al., 2017)

Intervention and design

The Hannafore Tile-Pool study integrated a grooved and water-holding precast concrete tiles retrofitted to a concrete storm water outfall pipe to make a simple walkway in the beach safer for humans and tidal species. The tile system traps small pools of water at low tide beneath a walkable and textured surface. The surfaces were designed to attract species which graze on the green algae which often builds up on artificial structures in the intertidal zone.

Figure 25 Eco-enhanced stormwater outfall at Hannafore beach

Monitoring

6-month colonisation assessment and public perception survey (n=25).

Outcomes

- Animal diversity tripled and algal diversity doubled on grooved tiles vs. smooth concrete in less than 6 months.
- Animal abundance increased 30-fold on the "wave" tile compared to the business-as-usual smooth concrete surface.
- In a survey of twenty-five respondents, 64% of respondents preferred the wave tile and perceived the greater ecological value; the site remained usable for walking and kayak launching.
- The design and results of monitoring are presented in the following PhD thesis: Metcalfe, D (2015) Multispecies Design, University of the Arts London, in collaboration with Falmouth University

Cost and buildability

- For this prototype, the cost of design, production and deployment of test tiles was approximately £2,000 (~£1,000/m^2).
- The only additional cost for future applications would be design and production of textured formwork during the construction phase.

Engineering and regulatory notes

- The test tiles did not compromise the engineering performance of the structure; pre-cast design and ecological colonisation of the wave tiles would not affect performance, inspection, or maintenance.

- It is thought that in zones where barnacles were in high abundance, the biology may improve asset resilience to weathering related deterioration without impacting on human use of the outfall as a footpath.

Key lessons

- Ecoenhancements can result in additional public benefits, the tiles in this example provided biodiversity benefits as well as an accessible path for the public.

Case 5 Ecological pile encasement, Brooklyn Bridge Park, NY, USA (Perkol-Finkel & Sella, 2015)

Intervention and design

Several piles at Pier 6 of Brooklyn Bride Park in Brooklyn required a structural repair in the form of concrete encasement or a 'jacket', for maintaining the load-bearing structural properties of the pile.

Ecological pile encasement was used for 18 of the piles which involved an innovative concrete mix that enhances the growth of marine flora and fauna (Perkol-Finkel and Sella, 2014). In addition, textured forms were applied and stripped after casting, imprinting a rough texture onto the surface of the concrete jacket, which induced rich marine growth.

Figure 26 (a) ecological jackets and (b) control - fiberglass jacket. Both are 14 months post-deployment.

Monitoring

All the ecological jackets, as well as three standard control jackets (Portland-based concrete with fibreglass form) at each face of the pier, were monitored 3, 10 and 14 months post-deployment.

Outcomes

- The ecological jackets enhanced the recruitment of marine organisms, creating a richer and more diverse habitat compared to the control fibreglass jackets that offer limited habitat value.
- Species richness on the enhanced jackets was double that found on the control jackets.
- Most of the species recruited onto the enhanced jackets were filter feeders like tunicates, sponges, and bryozoans, capable of contributing to water quality and clarity in the area.
- In addition, many of the species dominating the enhanced jackets were habitat-forming species such as barnacles, bryozoans and sessile polychaetes that add to the complexity of the habitat with time, provide food and shelter to fish and motile invertebrates such as crabs, which used the ecological jackets as nursing grounds.

Engineering and regulatory notes

- The ecological jackets provided all the functional and structural support required from a standard concrete encasement, yet with biological and ecological value.

Technique 5 - Bolt on precast panels and tiles

Case 6: Living seawall panels, Sydney Harbour, Australia

Intervention and design

‘Habitat tiles’ have been fixed to North Sydney’s harbour walls in Sydney Harbour. They have been installed on seawalls along Sawmillers Reserve and Bradfield Park in North Sydney, making it the largest retrofit of a Living Seawall in Australia, and potentially the world.

The ‘habitat tiles’ are designed to help make seawalls more ecologically sustainable by creating a more natural environment for marine life.

This follows a 20-year partnership between North Sydney Council and Sydney-based universities on making seawalls more ecologically sustainable.

Figure 27 Living Seawalls at Sydney Harbours. [Source: https://www.sustainabilityhackers.com/living-seawalls-to-bring-new-life-to-rushcutters-bay/]

Monitoring

Ongoing partnership between North Sydney Council and universities; monitoring of colonisation and performance.

Outcomes

Panels increase habitat complexity and support diverse assemblages relative to smooth seawalls. Research in Sydney Harbour showed that after two years living sea walls supported at least 36% more species than plain, unmodified seawalls, with as many as 85 species of invertebrates, seaweeds and fish living and growing on the panels.

Key lessons

The retrofit approach is compatible with existing walls at scale.

Case 7: Mumbles Sea-Hive, Wales

Intervention and design

The Mumbles Sea-Hive was a project to test the impact of different textures of retrofitted tiles on improving the biodiversity of a seawall.

Mumbles Sea-Hive was a Swansea University SEACAMS2 project in collaboration with Swansea Council and Amey plc. SEACAMS2 was part-funded by the European Regional Development Fund (ERDF) through the Welsh Government. It was supported by Reckli GmbH, CubeX Industries, JBA Consulting, Amey's chosen civil engineering partner Knights Brown Construction Limited, Natural Resources Wales (NRW), the Ecostructure project (Ireland Wales Cooperation Programme 2014–2022), GRRIP project (Horizon 2020) and the Greatest Need Fund (SU).

135 hexagonal tiles were installed along the Mumbles Sea defences. Each tile was designed to be around 50cm wide, with a variety of patterns. Some mimicking natural rock surfaces, others with geometric patterns, and some reflected the history of the local oyster industry. The aim was to test which patterns provided the best home for local sealife such as seaweeds, barnacles and other creatures.


Figure 28 Mumbles Sea-Hive tiles showing variation in tile design – images courtesy of Ruth Callaway from Swansea University

Monitoring

The colonisation was monitored by Swansea University for just over a year.

Outcomes

Following the experiment, Swansea Council decided on one of the patterns for the new wall. It is called 'Kerry', manufactured by the mould producer Reckli. The Kerry pattern performed well in the experiment, was seen as aesthetically pleasing, and Reckli was technically able to upscale the pattern to the size of the new seawall. It was decided to keep the hexagons in the new pattern because of the pleasant look, and during the experiment the gaps between the panels proofed to have a useful ecological function: limpets and periwinkles used them for shelter.

The new seawall was finished in 2025. The wall was quickly colonised with filamentous green algae (Ulva intestinalis). While this can be expected at the upper edge of the intertidal area, it is likely that the highly alkaline conditions of the fresh concrete currently hinder other seaweeds and invertebrates to colonise it. The PH will lower over time, and the colonisation of the new sea defences should increase over the coming years.

Key lessons

The project highlighted the benefits of trialling designs of ecological enhancement product to inform longer term design decisions.

Case 8: IJmuiden Breakwater, Netherlands (Borsje et al., 2011)

Intervention and design

One of the breakwaters ('Het Zuiderhavenhoofd') at the entrance of the North Sea Channel at IJmuiden (The Netherlands), which consists of concrete blocks of 22 and 30 metric ton embedded in asphalt, has been retrofitted with several tiles.

The tiles measured 75cm×50cm and the top surface was divided into six sections (25cm×25 cm), different in texture or geometric structure, that were tested for algal and macrofaunal colonization.

Two locations were selected: a 'low dynamic' and 'high dynamic' one in terms of wave attacks. In the high, middle and low part of the intertidal zone different types of tiles were mounted on the blocks from April 2008 to September 2009

Monitoring

Photos of algal/macrofaunal colonisation per section and elevation were analysed.

Outcomes

- Sections on the tiles with a fine or coarse surface were colonized more rapidly by small green algae than those with a smoother surface.
- The geometric structures, cup and holes, which retained water longer during low tide favoured the initial colonization by larger green algae.
- With time, the differences in algal density between the sections on the tiles became less obvious.
- All sections of the tiles in the mid and low tidal zone of both locations were rapidly overgrown by barnacles. Mussels were only found in the sections with grooves, holes and cup, and developed best within the grooves.

- Both grooves and holes were used by periwinkles for shelter at low tide.
- In general, tiles which were mounted low in the intertidal area showed a more rapid and diverse colonization, compared to the tiles which were mounted higher in the intertidal area.
- 3 out of 10 tiles in the high dynamic environment broke down and showed the importance to protect the tiles against extreme conditions.
- In conclusion, small adaptations of both texture and structure of concrete constructions within the intertidal zone of the marine environment led to better settlement and growth conditions for algae and macrobenthos

Key lessons

- Ecoenhancements can be vulnerable to physical damage from harsh coastal conditions.
- Design features to be durable for high energy sites and implement monitoring programmes to assess degradation and repair procedures.

Case 9: **Plymouth, UK**

Intervention and design

In 2023, a 12 x 2 m section of modular habitat panels were installed to enhance biodiversity on a seawall close to the Mayflower steps becoming the largest installation of its type in the UK. The panels are made of recycled marine-grade concrete.

The project was led by the University of Plymouth working alongside partners including Living Seawalls, Sydney Institute of Marine Science, Plymouth City Council, Tamar Estuaries Consultative Forum, Our Only World, The Rock Pool Project, Arup, Swansea University, and Ocean Conservation Trust.

Figure 29 Living seawall at Plymouth (Source: University of Plymouth)

The concrete panels were designed by Plymouth Sound National Marine Park.

Originally designed by researchers in Sydney, Australia, Living Seawalls are modular systems by which critical habitats for marine life can be added to marine constructions at scale. Using 3D printing technology, the pits, crevices and pools often present on natural shorelines are recreated on modular concrete panels.

The panels, which can be manufactured from upcycled materials, are then fitted to new or existing marine developments in customisable ‘Living Seawalls’ mosaics designed to last at least 20 years in locations of low wave exposure.

Monitoring

The panels have been actively monitored for ecological success by the University of Plymouth since their installation.

Funding

Funding partners included the University of Plymouth, Our Only World, Plymouth City Council, Tamar Estuaries Consultative Forum, Cattewater Harbour Commissioners, and Associated British Ports (ABP).

Key lessons

- The scale of ecoenhancements is increasing following early trials.
- Partnership work can facilitate funding and research opportunities
- Some types of ecoenhancement features can be made from recycled materials resulted in added benefits to the environment.

Case 10: Falmouth Harbour Habitiles and Reef Cubes (Technique 4 and 8)

Intervention and design

In 2024 Falmouth Harbour worked in collaboration with Cornish environmental charity Our Only World, Gwynt Glas Floating Offshore Wind Farm, Falmouth Town Council and ARC Marine to install sea wall habitiles and 14 reef cubes.

Habitiles and reef cubes are designed to withstand tidal forces whilst creating greater habitat complexity than traditional harbour walls, reef cubes also feature a central chamber which provides shelter for marine life and a built in rockpool on the top, which helps retain water at low tide. Both structures are made from carbon-neutral concrete and have been tested to ensure they do not harm the marine environment. Both interventions have been installed on and around the harbour wall.

Figure 30 Falmouth Harbour Before and After Reef Cube. source: ARC Marine

Figure 31 Falmouth Harbour Habitile Before and After. source: ARC Marine

Monitoring

A baseline survey of the unaltered harbour wall and surrounding foreshore was undertaken in March 2023 with regular surveys planned to monitor the change in biodiversity.

As part of a commitment to raising awareness, the Gwynt Glas floating offshore wind project team, engaged with local schools, alongside Our Only World, to educate students about the importance of the marine environment, biodiversity, and renewable energy. The sessions highlighted the importance of sustainable innovation and the associated regional career and business opportunities offered by floating offshore wind projects.

Funding

Our Only World provided and collated funding from Sea-Changers, Matthew Goode Foundation for the installation of the habitiles. Gwynt Glas Floating Offshore Windfarm funded the purchase of the Arc Marine reef cubes. Natural England provided funding for the baseline ecological survey completed by Cornwall Environmental Consultants. Falmouth Town Council provided funding to design and print interpretation boards.

Key Lessons

- Partnership work can facilitate funding and research opportunities.
- Combining techniques of ecoenhancements can result in greater benefits for biodiversity.
- The Reef Cube project at Falmouth Harbour demonstrates how ecological enhancement can deliver direct advantages to industry, particularly ports, offshore energy, and coastal infrastructure. The Reef cubes are designed to stabilise seabed conditions and reduce erosion (scour) around structures protecting features such as the harbour wall, extending asset lifespan whilst facilitating biodiversity enhancement through nature inclusive design.

Technique 6 — Bolt on precast vertical pools

Case 11 : Vertipools, Bouldnor Beach, Isle of Wight (Hall et al., 2019)

Intervention and design

During September 2013, five concrete wooden-cast Vertipools were installed between Mean Tide Level (MTL) and High-Water Neaps (HWN) on a vertical concrete seawall at Bouldnor, Isle of Wight. The shore at this location is moderately sheltered with a north facing aspect and a mean tidal range of 2 m.

The Vertipools weigh 50 to 70 kg and are 900 mm at their widest, 610 mm in height, protrude a maximum 400 mm from the seawall and have an undulating pool depth of 10–200 mm. See the Artecology website for more research papers featuring Vertipools.

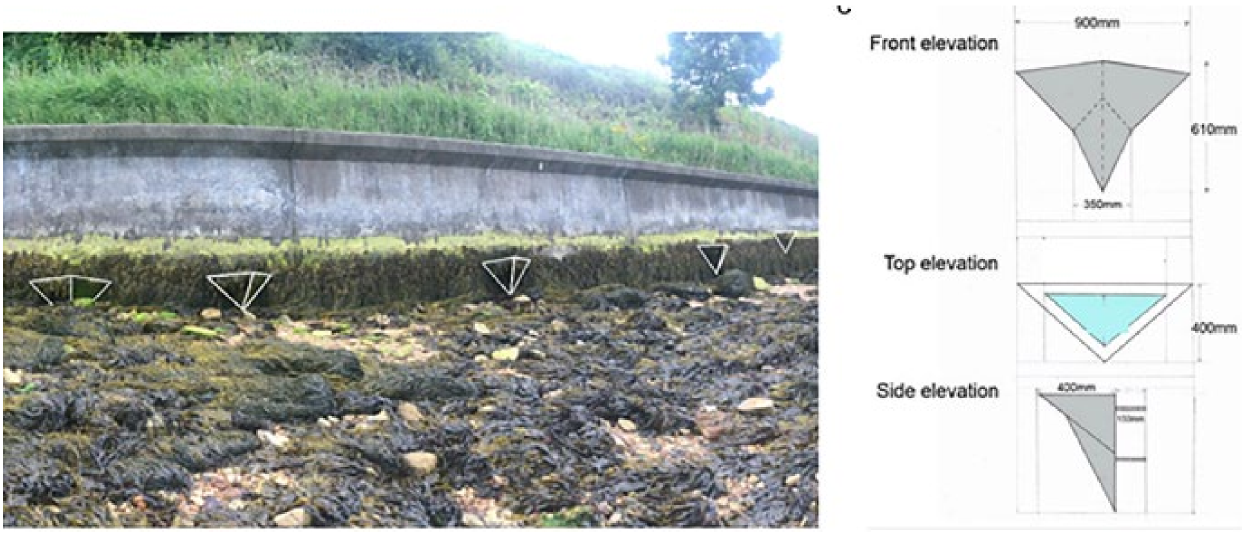


*Figure 32 Location of the original Vertipools on the seawall (left) and dimensions of the Vertipools (right) [*Source: From Hall et al. (2019)]

Monitoring

Five-year monitoring of interior and exterior communities vs. control and disturbed wall areas.

Outcomes

- Over 5 years, a total of 24 species were recorded on the inside of the Vertipools, 15 species were found on the outside of the Vertipools, 12 species on the control seawall and 8 species on the disturbed seawall adjacent to the Vertipools.

- The water retention and increased surface texture provided by the Vertipools created a habitat which was absent from the existing sea wall, enabling a variety of different rock pool species, including fish, to inhabit the structure. Within the study area, the Vertipools increased the species richness on the seawall,

- The Vertipool located at the greatest height on the seawall took longest to colonize, with the interior community predominately consisting of opportunistic algae, whereas the exterior was colonized by Fucus spiralis.

- Over the duration of the study, it was noticed that the elevation of fucoids on the exterior of the Vertipool increased to a height above that of the fucoids growing on the seawall, possibly due to the damper, shaded “overhang” effect created by the Vertipools.

- Overall long-term monitoring showed:

  -increased **species richness** vs. control surfaces
  -support for **new functional groups** (e.g. predators, grazers)
  -colonisation by **mobile fauna** (fish, crabs)
  -formation of **distinct ecological communities**

Engineering and regulatory notes

All the Vertipools remained attached to the seawall with no visible signs of damage; destruction of bolt-on enhancement units by waves has been a problem in previous studies (Browne and Chapman, 2014). The Vertipools were designed to deflect wave energy and the strong internal and external fixings ensured that no damage was caused to the Vertipools or the seawall.

Key lessons

Bouldnor represents an **early iteration** used to establish ecological performance.

Subsequent projects have built on this by incorporating:

- improved materials and integration
- expanded feature types
- community-led co-creation approaches

Case 12: Artificial rockpools- Bournemouth

Intervention and design

A team from Bournemouth University installed 114 artificial rockpools as part of the MARINEFF Project (MARine Infrastructure EFFects research project- 45 bolted on to harbour walls in Poole Harbour, 45 at Boulder on the Isle of Wight (described above) and 24 at Hamble Harbour, Southampton The artificial rockpools were manufactured by Isle of Wight based ecological enhancement company Artecology and were a new bespoke design for the Marineff project. Made with a metal bracket, the rockpools were able to be mounted on existing coastal infrastructure.

Figure 33 Vertipools at Poole Harbour Source: https://www.bournemouth.ac.uk/research/research-action/artificial-rockpools

Monitoring

For three years, the team have been monitoring the species that inhabit them and comparing the results to species residing on the sea wall.

Outcomes

65 different species were spotted making use of the 45 artificial rockpools installed on a seawall at Sandbanks, including the protected native oyster Ostrea edulis. Other species found include crabs, barnacles, molluscs, small fish, sea squirts and 25 types of seaweed. This compared to 40 species that were found in whatever cracks and crevices they could find on the harbour wall, showing that the rockpools are creating an additional habitat for marine life that would not be able to survive on the harbour wall without the rockpools.

Bournemouth University's (BU) MARINEFF project won the Habitat Creation Small Scale award at the CIRIA BIG Biodiversity Challenge Awards for its work creating and testing artificial rockpools.

Engineering and regulatory notes

The project was funded under the European cross-border cooperation Programme INTERREG VA France (Channel), as well as a €3.1 million contribution from the European Regional Development Fund (ERDF), the objective of the MARINEFF project was to develop a new approach to the design and construction of maritime infrastructure. MARINEFF strived to enhance and protect coastal and transitional water ecosystems in cross-border Channel regions.

Key lessons

- Vertipools can be successfully used at scale

- Biodiversity challenges, such as that led by CIRIA, highlight where industry can go beyond business as usual can support the uptake and sharing of information about best practice in the use of ecoenhancements.

Case 13 : Blyth Pier vertipools array, Northumberland

Intervention and design

Groundwork North East and Cumbria, in collaboration with Artecology and partners installed 36 Sandown-model Vertipools in a large triangle array on Blyth Pier to test how ecological enhancement interventions perform at scale on operational coastal infrastructure. The Vertipools were strategically placed to maximise the ecological benefits of the spaces between units, which act as valuable habitats alongside the pools themselves. This case represents a shift from single-feature trials to distributed, multi-unit habitat systems.

Figure 34 Blyth Pier Project. Source: Artecology

Figure 35 Blyth Pier Project array design of Vertipools installed in 2021 and 2023. Source: Artecology and Groundwork North East and Cumbria

Monitoring

Blyth builds on evidence from studies such as [Firth et al. (2016),] which demonstrated the effectiveness of artificial rock pools in enhancing biodiversity on coastal structures. See the [Artecology website] for more research papers featuring Vertipools.

Outcomes

- 20+ species were recorded within first year
- Rapid colonisation was found across multiple units
- Variation was found between pools, increasing overall diversity
- There was a visible transition from uniform surface to functioning habitat

1. Biodiversity Net Gain (BNG)
The Vertipool array has transformed the sterile seawall into a thriving intertidal habitat, supporting a diverse range of marine species. Early monitoring has recorded over 20 species, with expectations of further increases as the ecosystem matures.

2. Climate resilience
The installation provides a scalable solution to combat the effects of rising sea levels, offering a blueprint for future coastal adaptations in the UK and beyond.

3. Community engagement and education
The project has become a focal point for local engagement, with plans to involve schools, community groups, and media in educational initiatives. The array will also feature in upcoming documentaries and media coverage, highlighting its significance in marine conservation.

Key lessons

Uniform coastal structures limit biodiversity. Scaling up habitat features increases:

- habitat availability
- microhabitat diversity
- ecological connectivity

This reflects the principle that feature density and distribution influence ecological outcomes.

Delivered through a partner-led model, demonstrating:

- transferability beyond pilot sites
- adoption by external organisations
- integration into standard infrastructure projects

Technique 7 — Green Wall Modules

Case 14: Green wall modules, River Thames, London (Francis et al., 2015)

Intervention and design

The aim of the project was to evaluate the potential to improve the diversity of river walls and embankments along the River Thames through central London (and by extension other global estuarine urban rivers) by using modular living wall technology.

The wall modules consisted of plastic cups housed within a durable plastic frame. These were filled with soil and sown with Gypsywort and Marsh yellow cress to attempt to establish some coverage of vegetation prior to installation. A layer of coir was placed over the cups, which was in turn covered by a fine wire mesh that allowed seeds to be deposited but which was intended to prevent clods of sediment/soil being easily washed out by the river flow. The modules were 25cm X 50cm allowing them to be easily attached to each other.

Wall modules were installed at six sites owned by the Crown Estates along the Thames, from upstream to downstream. The original intention was to have modules mounted at two elevations – above and below mean high tide. However, this was not possible due to obstructions at particular sites. Instead, height above foreshore was recorded for each module, so that any relationship between position and species richness or abundance could be determined. All sites had wall modules positioned vertically on the walls, except for one, where the wall sloped at an approximate 45^{o} angle.

Figure 36Vegetation cover at the wall modules at Kew Bridge Site (Source: Francis, R. 2015)

Monitoring

After installation, the wall modules were surveyed approximately once every four weeks, between January 2013 and October 2014.

In addition, questionnaires were distributed to understand the public's perception of the Thames walls, their response to the wall modules, and their response to other forms of ecological engineering utilised along urban rivers.

Outcomes

- Vegetation establishment of the wall modules was disappointing for the sites with vertical wall modules.
- Only the site with wall modules installed at 45^{o} angle maintained both a good level of plant coverage and species richness throughout the project. This is supported by the significant differences found for both species richness and percentage plant cover.
- The main factor driving the variation was probably that the modules at this site were sloped, and therefore this may represent an important recommendation for further interventions of river hard infrastructure involving river wall modules – vertical orientation is unlikely to provide long-term success, at least utilising the current design.
- Data from this project suggest that module size and position above the tide line have little influence on plant establishment. These factors do influence plant establishment on the walls more generally (e.g. Francis and Hoggart, 2009) and were expected to exert an influence in this project, but the poor performance of the modules may have limited the evidence to support this trend in this case.
- In general, a higher proportion of wetland/riparian plants was found on the modules compared to previous surveys of the walls (especially the concrete and sheet piling walls upon which the modules were installed). This means that with sufficient

coverage of walls with the modules, and ideally with a less than vertical orientation, increasing habitat area may be provided for wetland and riparian plants.

- The questionnaires revealed a general positive opinion of wall vegetation, and substantial support for habitat enhancements. There was wide recognition that wall vegetation was beneficial to wildlife, but that the vegetation might damage the walls or trap litter and therefore be unappealing. Opinion was expressed that support for installations would be highest if enhancements could support abundant vegetation so that the underlying modules etc. were not readily apparent, and if they did not make the walls appear untidy or neglected.

Key lessons

- Orientation (non-vertical) appears critical for plant-based modules.
- Aesthetic integration can increase public acceptance.

Technique 8 — Drop-in prefabricated units

Case 15: BIOBLOCK Prototype, Colwyn Bay, Wales (Firth et al., 2014; Naylor et al., 2017)

Intervention and design

A new coastal defence scheme including the construction of rock revetments and a shore perpendicular groyne was completed on the north-facing beach at Colwyn Bay, Wales in 2012. A prototype habitat enhancement unit, called the BIOBLOCK was installed into the new groyne. The BIOBLOCK is a large, precast habitat-enhancement unit comprising multiple habitat types that would not normally be present on the boulders of a structure. The purpose of the BIOBLOCK is to provide habitat whilst still dissipating wave energy. Design parameters were as follows:

- The prototype unit was 1.5 m × 1.5 m × 1.1 m, weighed 5.4 tonnes and comprised rock pools, pits and grooves habitats in the vertical and horizontal faces.
- 12 artificial rock pools were created with differing diameters (large: 25 cm diameter and small: 15 cm diameter) and depths (deep: 20 cm and shallow: 10 cm).
- Pits and ledges were incorporated into the remaining four vertical sides.
- On two of the vertical faces of the unit, four patches (25 cm × 25 cm) of sixteen evenly spaced pits (deep: 5 cm and shallow: 2 cm) (two of each on each face=8 patches in total) were included.
- On the other two vertical faces, ten horizontal grooves (5 cm × 5 cm × 100 cm) were evenly spaced along the length of the face (20 grooves in total).

Figure 37 BIOBLOCK [Source: Naylor et al. (2017)]

Monitoring

All biota in the different habitats (including the surrounding boulders) were identified and monitored monthly for thirteen months.

Outcomes

- The BIOBLOCK consistently supported greater species richness than the adjacent boulders.
- Functional groups represented across all months on the BIOBLOCK included algae, barnacles, shrimps, annelids, crabs, ctenophores and gastropods whilst those represented on the adjacent boulders included algae, barnacles and crabs.
- After thirteen months, the BIOBLOCK supported a total of ten species whilst the adjacent rocks supported only four species.
- On the BIOBLOCK, the large deep pools supported a total of five species, followed by the small shallow pools and ledges (four species each), big shallow pools, small shallow pools and deep pits (three species each), and shallow pits supporting the lowest species richness (two species).
- The vertical and horizontal faces of the adjacent rocks supported four species each.
- It appears that the greater variety of novel micro-habitats on the BIOBLOCK supported greater species richness than comparable adjacent boulders, primarily because of the availability of multiple habitat types on the BIOBLOCK.

Cost and buildability

- The cost per BIOBLOCK unit was £2,000 for the mould, casting, transport and deployment which is equivalent to £800/m3. This compares to between £63 – 93/m3 for rock groynes (EA 2015, 2010 prices).

- The BIOBLOCK is between 9 – 13 times more expensive per unit compared to business-as-usual rock armour units used in rock groynes.

- Mass production of the BIOBLOCKS would reduce their costs

Engineering and regulatory notes

Expert judgement by engineers assumed no impact on engineering function of the groyne rock revetment.

Key lessons

Precast habitat-enhancement units such as the BIOBLOCK should incorporate multiple novel habitat types (pools of differing depths and diameters, pits of differing depths, ledges, and overhangs) to maximise species diversity.

Case 16: Teats Hill, Plymouth, UK

Intervention and design

Five BIOBLOCKs were deployed on the coastline at Teats Hill. Each measuring a cubic metre and weighing around 2.4 tonnes, they feature a range of holes and depressions designed to replicate a rocky intertidal area.

The BIOBLOCKS were designed to raise awareness of the potential benefits of artificial reefs in the marine environment. The units were specifically positioned by the slipways at Teats Hill so they could be observed by the public.
The installations were positioned to raise awareness off the potential benefits of artificial structures in the marine environment. To coincide with the installation, a temporary exhibition - also funded by the Marine Institute – was opened in the National Marine Aquarium. It featured a scaled down version of the blocks and information on how artificial reefs could potentially work.

Figure 38 BIOBLOCK being lifted into place and marine life growing in a pool on one of the BIOBLOCKs [Source: https://www.plymouth.ac.uk/news/bioblocks-show-how-coastal-designs-could-benefit-marine-life]

Monitoring

Researchers at the University of Plymouth are working with the National Marine Aquarium, ARC Marine and Plymouth City Council to incorporate some of those measures into the wider regeneration of the Teats Hill foreshore.

Outcomes

- Units feature varied holes and depressions replicating rocky intertidal microhabitats; used as educational assets.

Engineering and regulatory notes

- Positioned for observation; not reported to affect nearby infrastructure.

Key lessons

- Public engagement is a critical success factor in ecological enhancement schemes, influencing design quality, acceptance, and long-term effectiveness.
- Engagement helps communities understand why ecological enhancements (e.g. rock pools, textured armour) are included in coastal engineering projects and how they benefit biodiversity without reducing protection.

Case 17: Newlyn Breakwater (Newlyn coastal research and development project - GOV.UK)

Intervention and design

Between 2022 and 2023, the Environment Agency, alongside ARC Marine, installed 88 low-carbon eco-blocks—including ARC's Intertidal Reef Cubes®—at the Newlyn Breakwater in Cornwall as a partial replacement for rock armour. The aim was to add biodiversity value to a high energy environment whilst protecting the coastline. Reef cubes ® have been designed to add complex surface textures, internal shaded rockpools and vertical wall water retaining features. The features were made using low-carbon concrete, local industrial waste products were utilized in their construction to reduce the carbon footprint.

The Environment Agency placed miniature eco-blocks near the breakwater and monitored them for 2 years before constructing the full-scale pilot.

The project was mainly funded by EU Interreg's Sustainable and Resilient Coastal Cities (SARCC) project. Extra funding came from UK government FCERM grant-in-aid.

Figure 39 Eco-blocks colonised with marine life (Source: Environment Agency)

Monitoring

The Environment Agency are monitoring the eco-block's ability to withstand the high-energy environment and the effect of block size and orientation. Ecological surveys are carried out every 6 months. Regular asset monitoring is undertaken to inform maintenance needs.

Outcomes

Since construction in 2023 monitoring has shown the eco-blocks being colonised by marine life. For example, algae including purple laver has grown on the surface, and fauna such as snails, limpets and fish are using the habitat features.

Key lessons

- The benefits of trialling smaller structures in situ can inform final design.
- Joint partnerships can be identified to fund installation.
- You can email the Devon, Cornwall and Isles of Scilly enquiries team at the Environment Agency to find out more about the Newlyn coastal research and development project

Case 18: Hengistbury Head (Marine enhancements - South West Flood and Coastal)

Intervention and design

The Long Groyne at Hengistbury Head needed to be repaired and upgraded in order to continue being effective at reducing coastal erosion.

The long groyne at Hengistbury Head is critical in reducing coastal erosion in the surrounding area and was originally constructed in the 1930s, but with rising sea levels and storm events, the structure was found to be in poor condition, frequently submerged and ineffective. The groyne needed to be recreated in a taller and wider format and also included environmental enhancements. The granite rock armour traditionally used in groynes and other coastal defences lacks habitat value for marine life and the transport of it is typically very high in emissions. Often environmental enhancement units are made from concrete, which also has high carbon emissions, accounting for some 8% of annual CO_2 emissions on a global scale.

13 of ARC marine's low-carbon Reef cubes® were deployed around the enhanced Long Groyne in order to enrich marine biodiversity in the area with their Nature Inclusive Design (NID) which features a complex surface texture.

Figure 40 Installaion of ARC marine's low-carbon Reef cubes® (Source: ARC Marine)

Monitoring

Since the works at Hengistbury Head Long Groyne were completed in October 2024, the features have been regularly monitored. Inspections have shown that the upgraded structure has performed well across significant winter storm conditions, giving confidence in its long-term design life.

Outcomes

The marine ecological enhancements installed as part of the Long Groyne project design already have a variety of marine growth. Surveying of their success will continue over the next few years.

The project won an award at the ICE South West Civil Engineering Awards 2025 where it was described as "one of the UK's most environmentally ambitious coast protection schemes, combining innovative engineering with large-scale marine biodiversity enhancements".

Key lessons

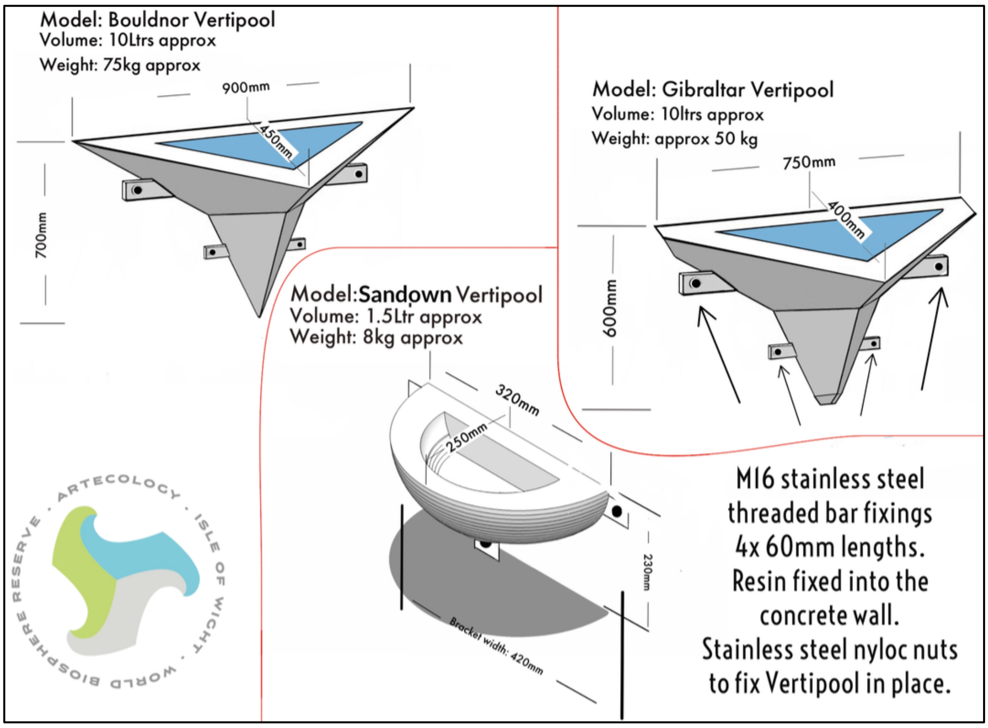
- Combining ecoenhancements techniques can result in greater benefits for biodiversity- A number of environmental enhancements were incorporated into the design of the upgraded long groyne in 2024, promoting biodiversity by creating complex habitats for fish, invertebrates, and algae.

- Further information on the range of ecoenhancements installed at Hengistbury Head can be found here: Hengistbury Head Long Groyne works 2024 - South West Flood and Coastal

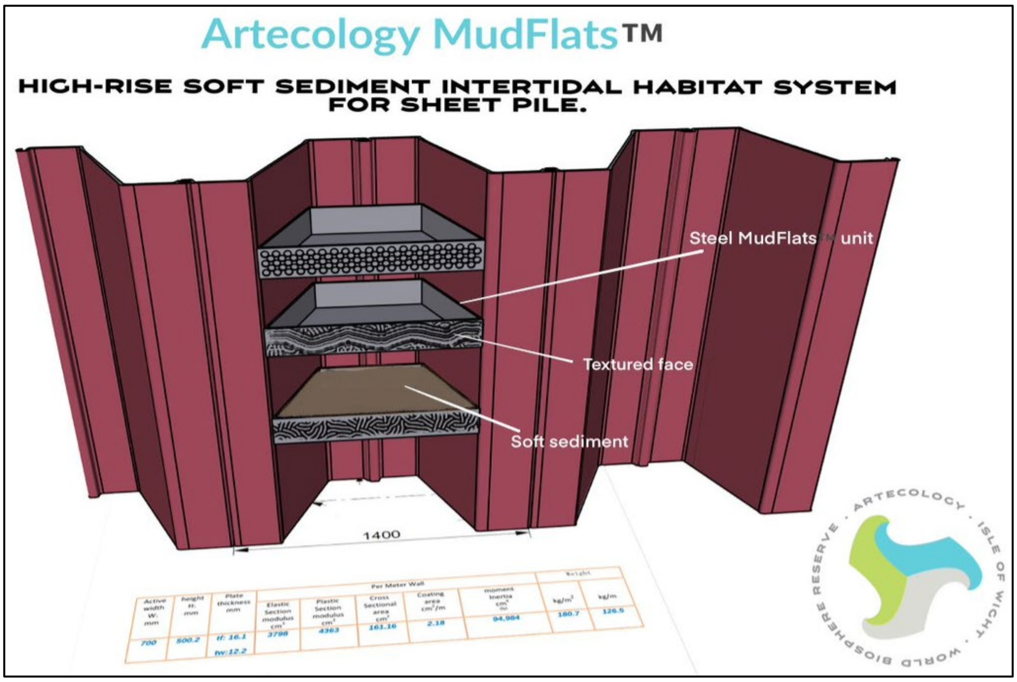
Appendix 2 Examples of ecological enhancements

Artecology

Example of vertipools

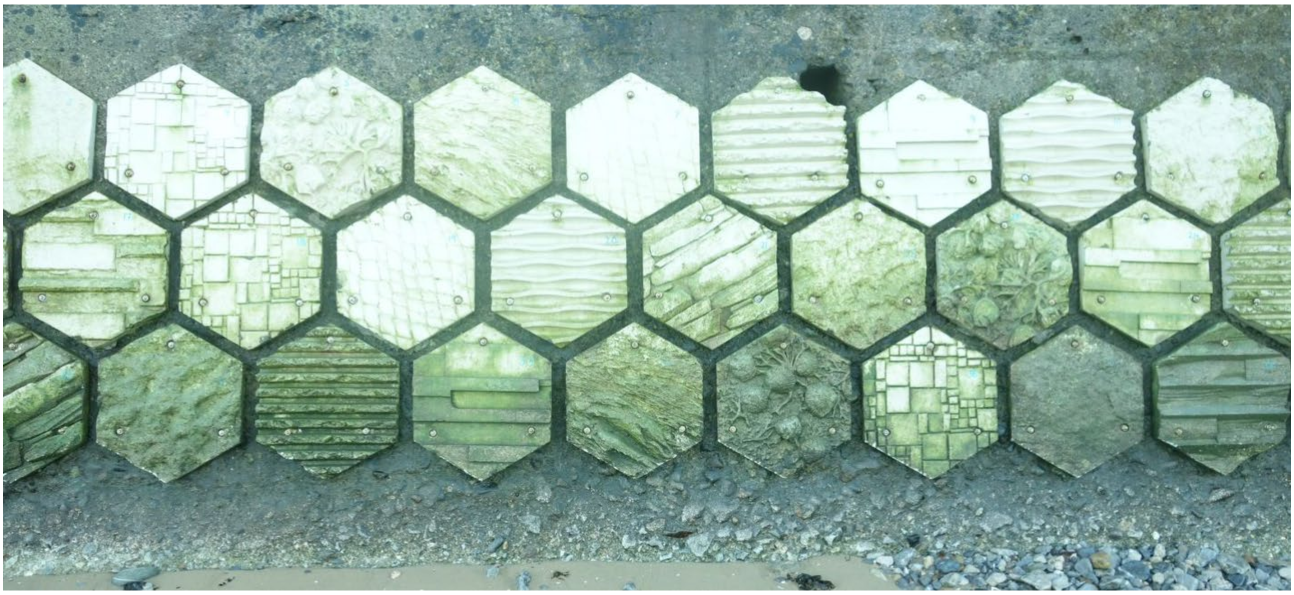


Example of MudFlats



CubeX

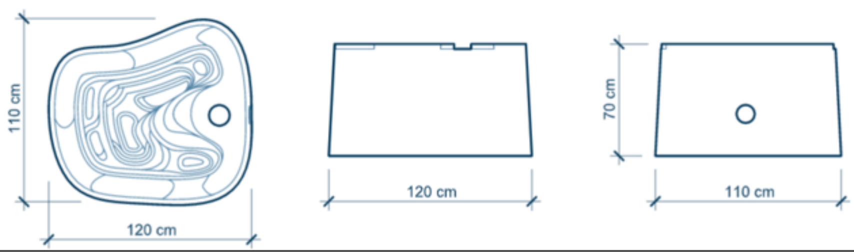
Example of Mumbles Sea Hive panels



Econcrete

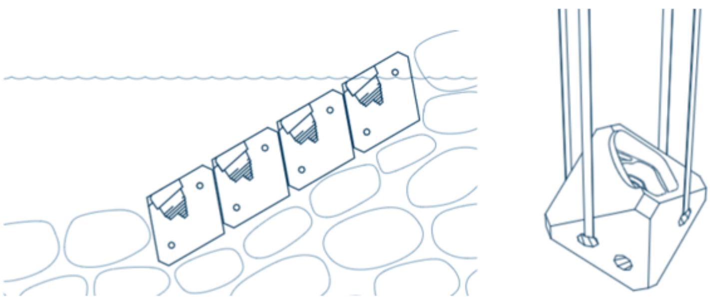
Example of Tide Pool

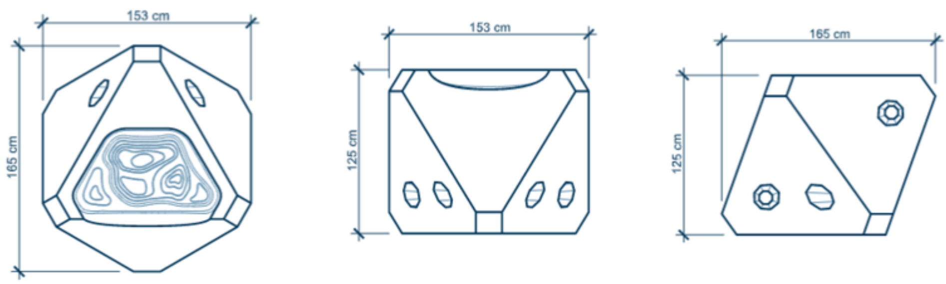
Length	Width	Height	Volume	Weight
120 cm (~4")	110 cm (~3.6")	70 cm (~2.3")	600 L (~0.8 yd³)	~1,400 kg* (~3,100 lbs)



Example of Coastalock

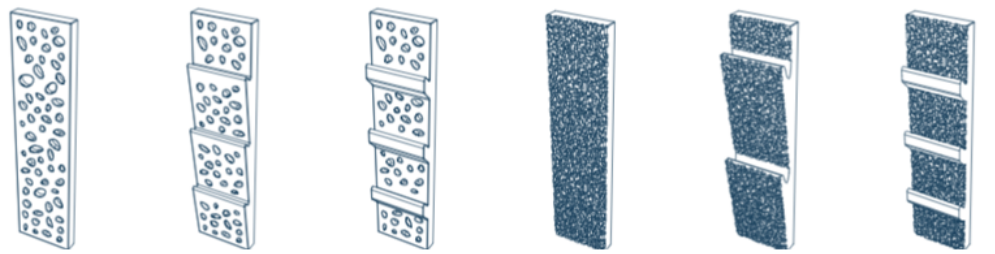
Length	Width	Height	Volume	Weight
165 cm (~65")	153 cm (~60")	70 cm (~49")	1,420 L (~50 ft³)	~3,410 kg* (~7,515 lbs)

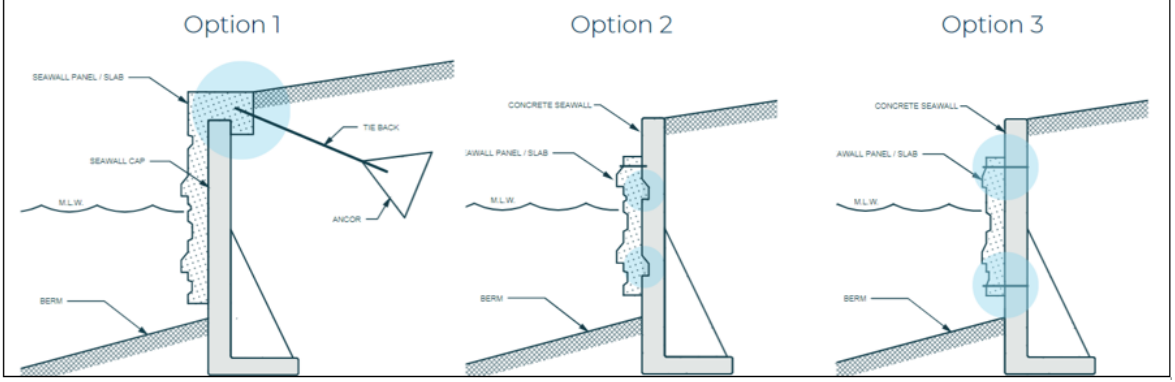




Example of Sea Wall Panels

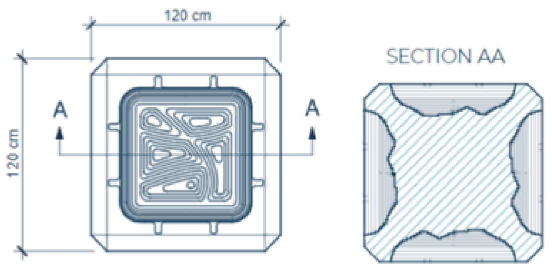
Width	Thickness	Height	Volume	Weight
100-200 cm (~3'-6')	10-40 cm (~0.3'-1.2')	100-400 cm (~12.2'-13')	3,300 L (~4.2 yd^3)	~7,700 kg* (~17,400 lbs)

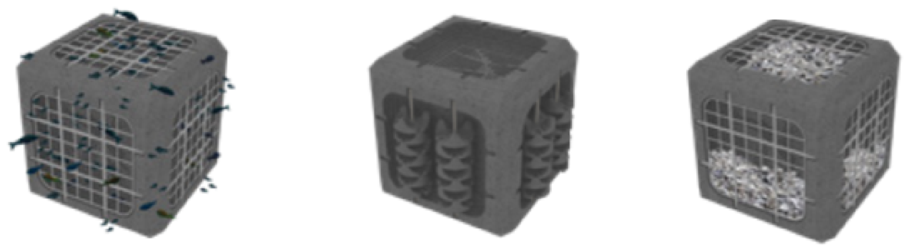




Example of Armor Blocks

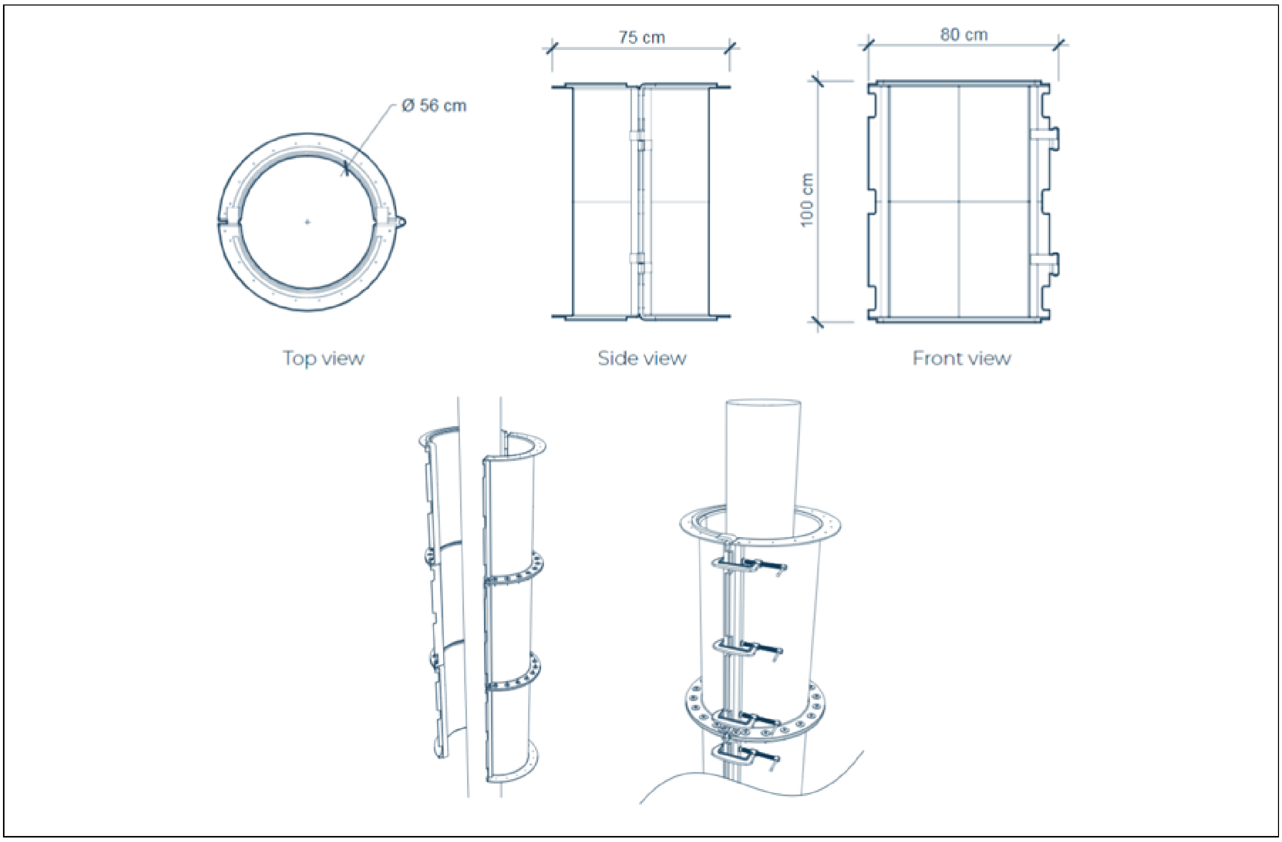
Length	Width	Height	Volume	Weight
120 cm (47")	120 cm (47")	120 cm (47")	1,150 L (1.51 yd^3)	~2,760 kg* (~6,085 lbs)





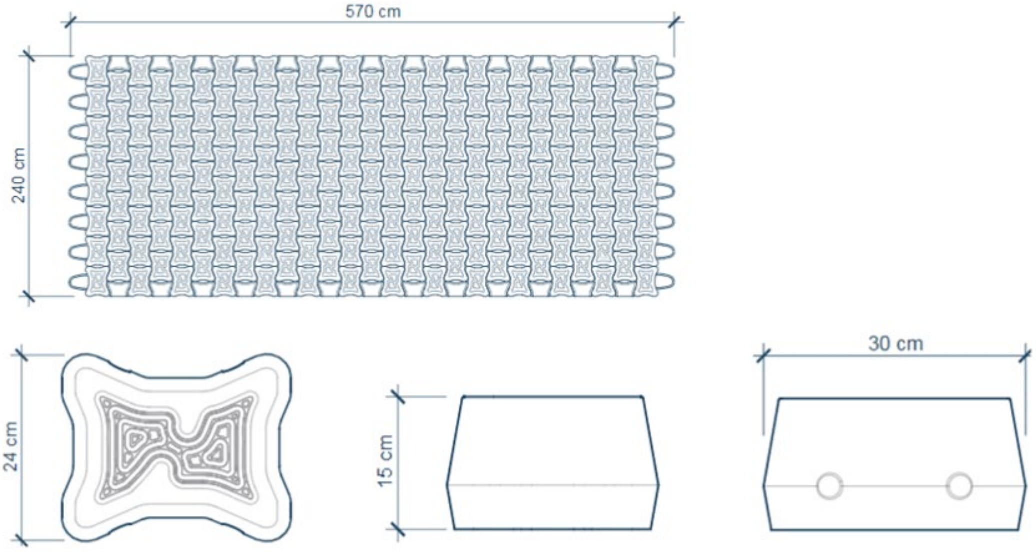
Fish Hubs Oyster Shell Oyster Hatchery Unit

Example of Pile Jackets



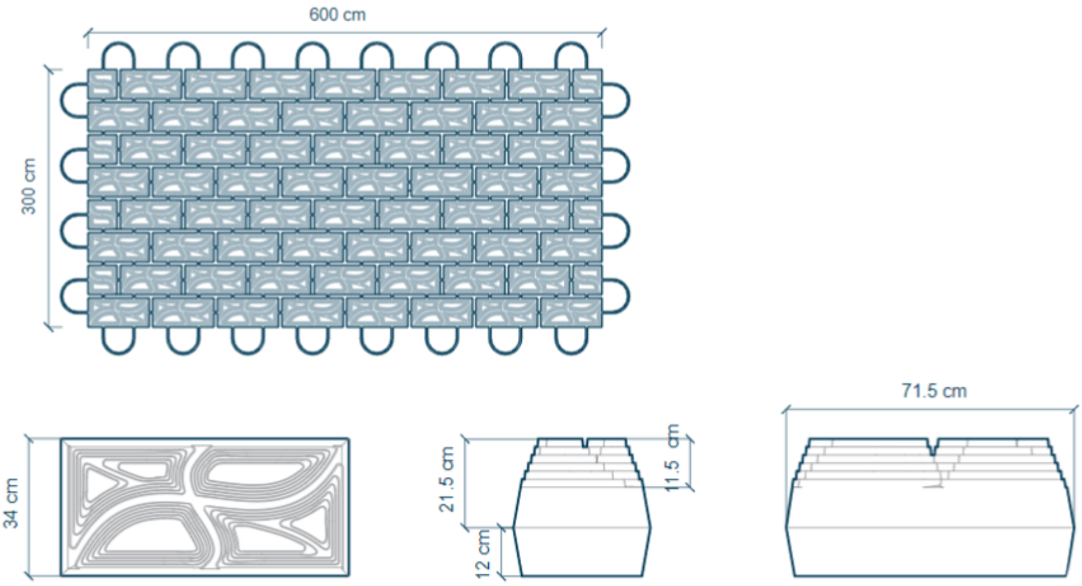
Example of Articulated Concrete Block Mattress

Length	Width	Height	Volume	Weight
570 cm (225")	240 cm (95")	15 cm (6")	1,540 L (2 yd²)	~3,700 kg* (~8,160 lbs)



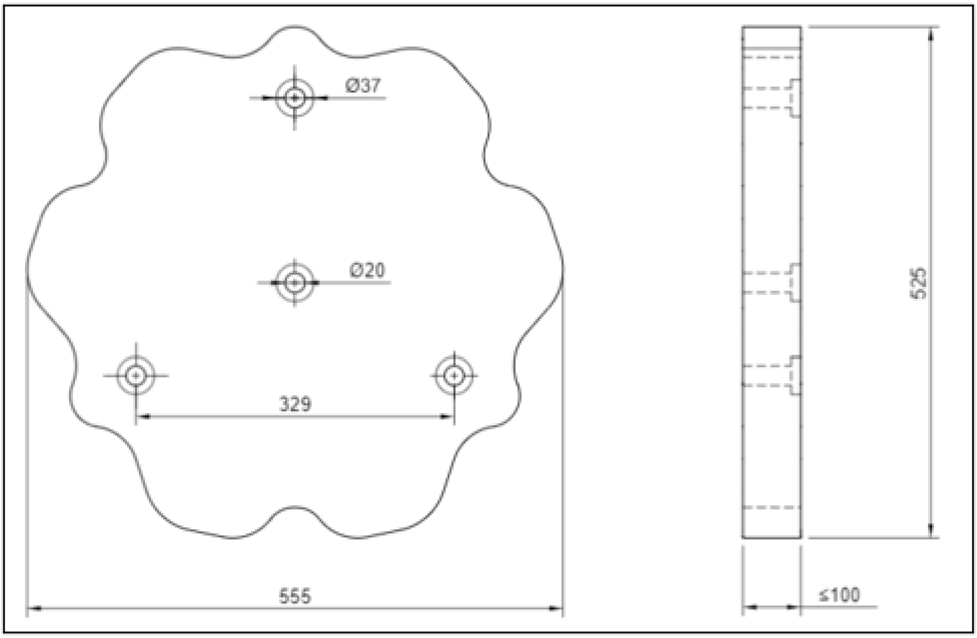
Example of Marine Mattress Wet Cast

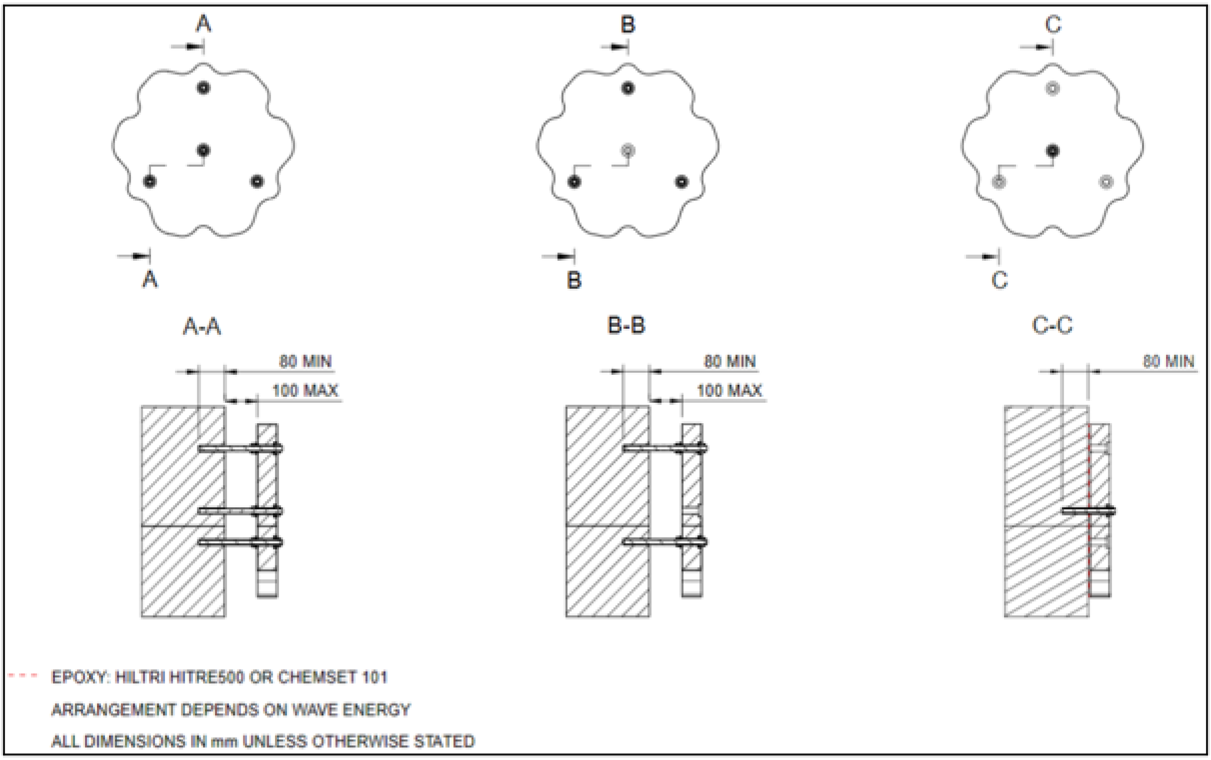
Length	Width	Height	Volume	Weight
600 cm (~236")	300 cm (~118")	33.5 cm (~13")	4,096 L (~3 yd²)	~9,830 kg* (~21,671 lbs)

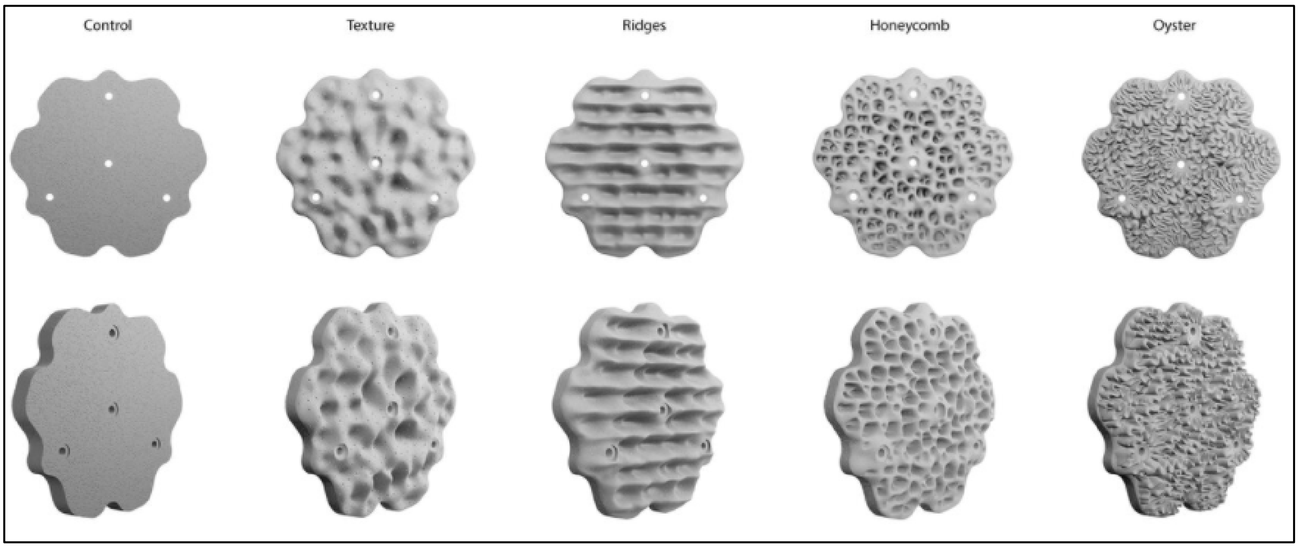


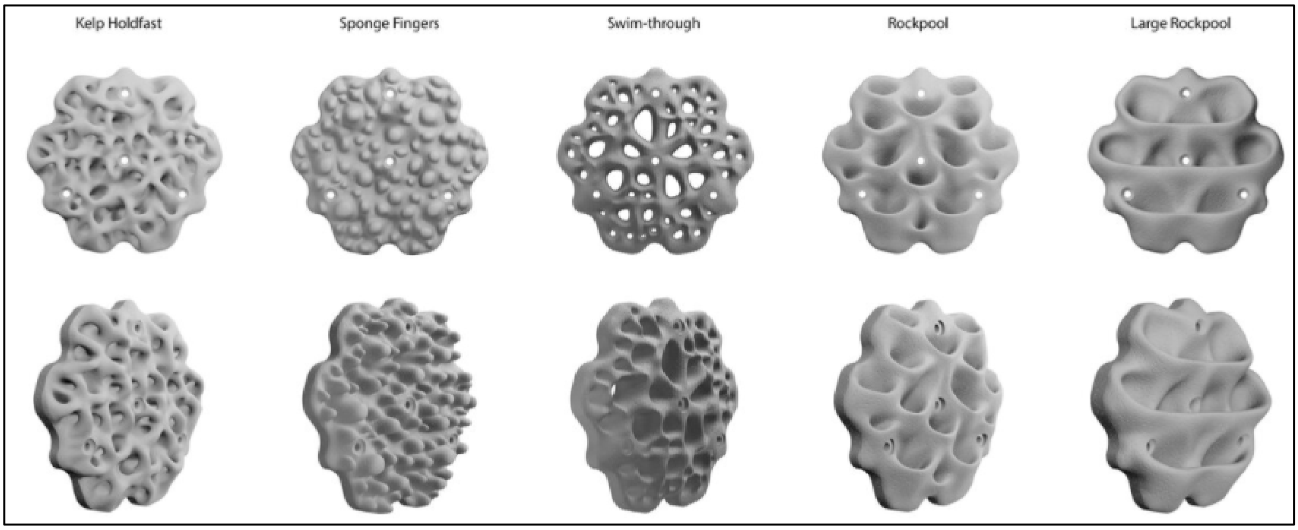
Living Seawalls

Example of Living Seawalls Panel



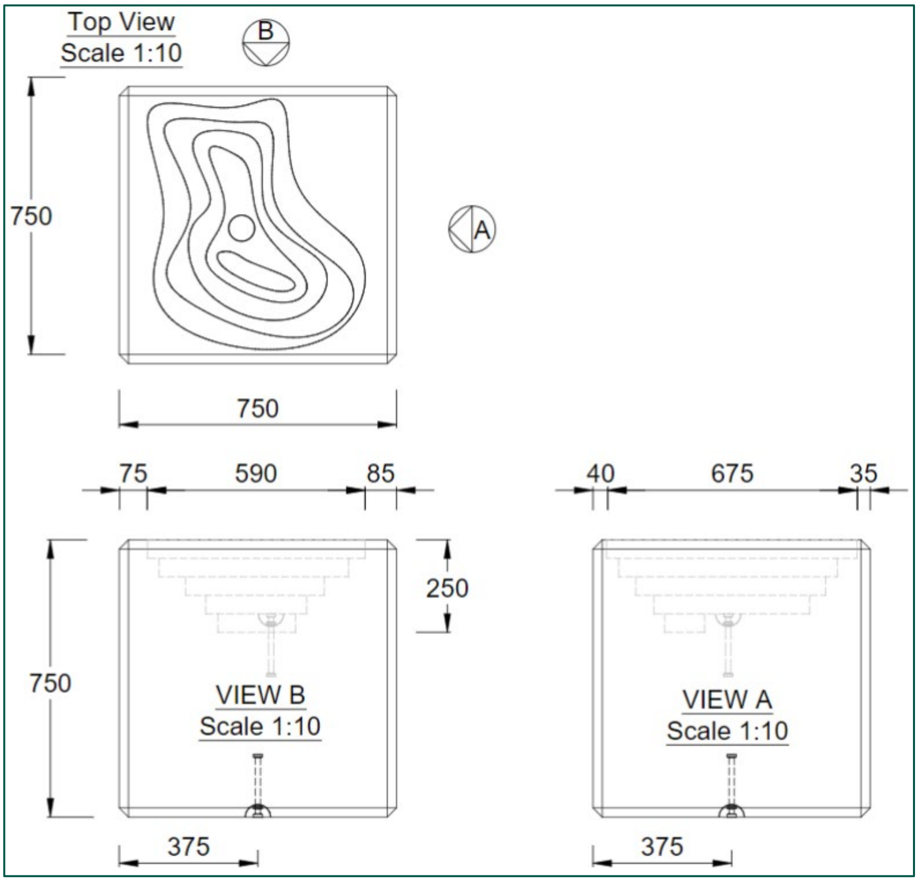



Control
Texture
Ridges
Honeycomb
Oyster


Kelp Holdfast
Sponge Fingers
Swim-through
Rockpool
Large Rockpool

JP Concrete

Example of Breakwater Eco-Armour



1. **Design & Manufacture**

a) Design Life: 50+ years.
b) Tolerances: ± 5.0mm in all dimensions according to BS EN 13670:2009.
c) Manufacturing to BS EN 13369:2013.

2. **Concrete**

a) Lifting cube strength = 15 N/mm².
b) Characteristic 28 day cube strength = Minimum of 40 N/mm².
c) Type: CEM III/A

3. **Reinforcement**

a) None. Can be added to client's request.

b) Finishes

	Top	Other
Class	Steel Float	N/A*

* Biomimicry design applied to other faces.

5. **Handling**

a) For Site Lifting details refer to JP Concrete's handling guide.
b) Unit Volume / Weight:

Unit	Unit Volume (m^3)	** Unit Weight (assuming 2.4T/m^3)
A	0.42	1.0 Tonnes ±10%

** Weight to be checked by the main contractor.

Note: The weights and volumes presented above are an estimate, the final product will depend on the Biomimicry design used.

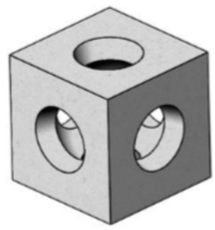
c) Anchorage: DEHA pin anchors, size to suit unit weight.

ARC Marine

Example of Reef Cube

REEF CUBE®

DATASHEET



☐ Made from 98% recycled materials.

☐ 100% plastic free.

☐ Carbon neutral - contains no Portland cement.

☐ Certified as non-toxic to the marine environment.

☐ Strength > $35N/mm^2$ (> 35MPa).

☐ Encourages marine growth / biodiversity.

☐ Multiple marine applications

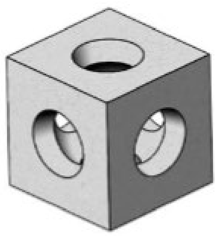
Reef Cube Model	L Length (mm)	W Width (mm)	H Height (mm)	M Weight in Air* (kg)	A Chamber Dia. (mm)	B Port Dia. (mm)	T Dimension Tolerance
RC15	150	150	150	4	130	60	D1
RC25	250	250	250	25	220	125	D1
RC30	300	300	300	40	200	150	D1
RC50	500	500	500	165	300	220	D1
RC75	750	750	750	540	500	375	D1
RC100	1000	1000	1000	1250	750	500	D1
RC150	1500	1500	1500	5200	1000	650	D1

*Weight in air based on a typical average density of $2,150kg/m^3$.

*Densities typically range from $2050\text{-}2250kg/m^3$. For bulk orders we manufacture locally hence product density & weight is subject to local variation of the sustainably sourced aggregrate.

HYBRID PYRAMID®

DATASHEET



☐ Deliberate marine habitat enhancement

☐ Encourages marine growth / biodiversity.

☐ Provides elevated chambers and substrate

☐ Designed for cod, cephalopods and sharks

☐ Made from 98% recycled materials.

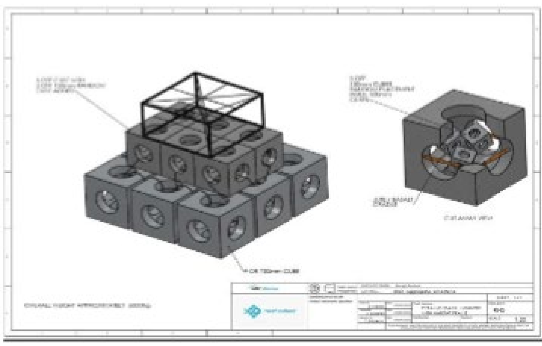
☐ 100% plastic free.

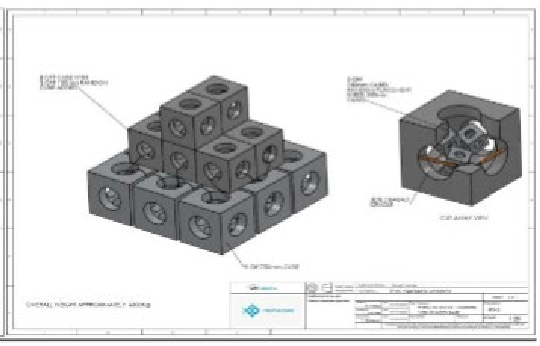
☐ Carbon neutral - contains no Portland cement.

☐ Certified as non-toxic to the marine environment.

☐ Strength > $35N/mm^2$ (> 35MPa).

☐ Stable under typical North Sea conditions.

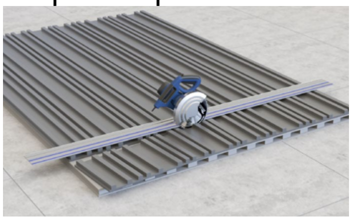




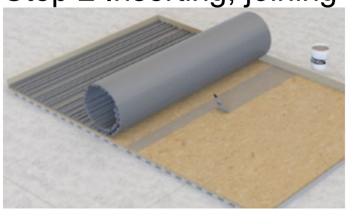
Reckli

Application guide example

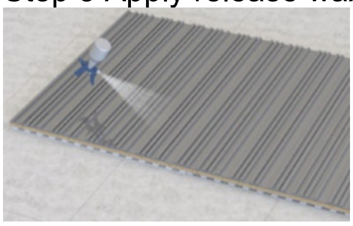
Step 1 Prepare the mould + 2 Preparing the formliner



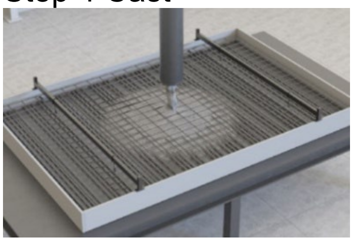
Step 2 Inserting, joining and positioning formliners in the mould and affixing the formliners



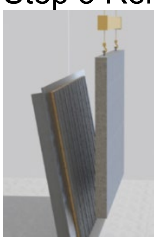
Step 3 Apply release wax



Step 4 Cast



Step 5 Remove and then clean the Formliner



Appendix 3 Coastal ecological ecoenhancement projects in Welsh waters Project Assessment Form

1. **Project details**

Information type	**Details**
Project title	
Lead applicant's details	
Name	
Address	
Telephone number	
Email	
Organisation	
Position	
Project partners	
Partner 1	
Role	
Partner 2	
Role	
Partner 3	
Role	
Additional partners and roles	
Is the project part of a wider initiative?	

2. **Project overview (Share this on the Marine Enhancement Directory - https://mend.eco/ to support wider uptake/ learning)**

Information type	**Details**
Type of Artificial Structure enhancing	*E.g. Sea wall*
Baseline Habitat	*What is the natural habitat of the shore*
Target Feature	*What habitat are you trying to create*
Enhancement Type	*E.g. creating rockpools*
Location	*Where is the planned project? E.g. site name, coastal / marine area name and region of Wales?*
Project Extent	*Size of habitat to be created*
Timescales	*When would site preparation start, key milestones and outcome timescales?*
Method Overview	*What method will be used for the proposal?*
Supplier Details	*Who is supplying the ecoenhancement product?*

3. **Project Rationale (Chapter 5 – Step 1 and 7)**

Objective	Detail
Primary Enhancement Objective	*What is the desired overall outcome of the project specific to the enhancement habitat / species? E.g. to increase extent, biodiversity or water quality. What is the wider conservation / climate rationale?*
Secondary Objective	*Refine the primary objective into more tangible objectives*
Secondary Objective	blank

4. **Site Profile (Chapter 5)**

Information type	Details
Asset Information (Step 2)	*What is the structure type? Is it a new build? What is the design life? What is the maintenance?*
Target Habitats/ Species	*What habitat/ species is trying to be created?*
Baseline Habitat (Step 3)	*What is the baseline habitat like? What microhabitats are present? What is the surrounding habitat?*
Environmental Baseline (Step 4)	*What are the baseline characteristics of the shore? What is the baseline hydrodynamic and sediment transport processes? What information has been used to inform the site suitability? E.g. site-specific baseline survey or wider monitoring schemes, evidence of historical or existing habitat or species population and/or available site-specific data.*
Anthropogenic Pressures (Step 5)	*Are there any ongoing constraints to enhancement success in the area? What activities cause these constraints? Consider both activities on site and those at distance that may impact the area. How well understood is the extent of the activity and how it directly impacts on the feature?*
What is limiting the target biodiversity condition? (Step 6)	*What is limiting the target biodiversity/condition? Lack of shade, wind exposure, water retention, wave exposure, etc*
What is the method of intervention that will be carried out? What are the design parameters (Steps 8-10)	*Material, size and shape*

Information type	Details
Who will supply the coastal eco-enhancement? (Step 11)	*Decide if any existing **products** suit the needs of the project (based on the chosen intervention(s) and most appropriate technique for the asset) or if non-specialist suppliers are more suitable.*

5. Regulation and Management (Chapter 6)

Information type	Details
Protected Areas	*Is the site located with a designated area? E.g. a Marine Protected Area, Special Protection Area, Special Conservation Area, Site of Special Scientific Interest or a Ramsar site?*
Activities	*What activities are being undertaken that may be regulated by the authorities and to what extent have these been considered?*
Landowner and Access	*Who owns this site and has permission been sought from the owner? What are the rights to access?*

6. Risks

Information type	Details
Initial Risks Assessed	*To what extent have risks been assessed considering current and presumed current threats to the feature? This may just assess risks to the species' biological attributes, else may extend to feature life history, wider ecosystem and socioeconomics, as well as different geographic scales.*
Climate Change Resilience/ Adaptation	*By what means has the current and future climate been considered for the proposal and how will this affect the site? E.g. how will the site adapt to future sea-level rise, temperature change, terrestrial flooding, water table, wind and extreme events.*
Risks Management and Mitigation	*In what manner will the potential risk(s) be mitigated against or managed? E.g. compensate for damage / /loss caused by a particular activity.*

7. **Benefits (Chapter 7)**

Information type	Details
Potential Benefits Assessed	*To what extent have the benefits of the proposal been assessed? This may include information and examples of biological benefits, ecosystem services, socio-economic benefits, cumulative benefits or nature-based solutions to climate change.*

8. **Engagement (Chapter 8)**

Information type	Details
Who needs to be consulted/ engaged with and why	*To what extent has engagement and consultation been considered to date? Who has been consulted and for what purposes, e.g. regulators, community groups and organisations involved in previous work at the site?*
Method of consultation/ engagement and timeline	*What type of communication channels/ methods will be used and over what timeline*

9. **Management, Monitoring and Evaluation (Chapter 5, Step 12)**

Information type	Details
Funding	*What finances have been secured for the project? What is the total cost anticipated for the duration of the project?*
Project Implementation Plan	*How will the project be implemented and how will this be managed? E.g. consider Management Action Plans, Working Groups, intervals between meetings and adapting objectives or adapting management measurements plan, or activating an exit strategy.*
Site Pressure Management	*How will the site pressure be managed? E.g. what activities will be undertaken to ensure the pressure(s) have been removed or reduced at the site to allow for a success? E.g. consideration of both current and future anthropogenic and natural pressures, such as disturbance effects*

Information type	Details
Monitoring Requirements	*To what extent have you considered how the site will be monitored? E.g. length of monitoring program, elements of the site that will be monitored, timescales and intervals, comparison with wider ecosystem or monitoring of self-sustainability of the site.*
Site Monitoring Logistics	*How will you carry out and resource monitoring at the site to allow measurement of outcomes over time, including beyond the initial restoration phase*
Establishing Success	*What measures will be used to determine how the primary objectives have been achieved? Please include any means of measurement, parameters or metrics, and how often they will be measured E.g. quantify the anticipated increase in habitat area, change in target community, population numbers, density, or nutrient reduction levels, etc.*
Lessons Learnt	*How will the lessons learnt be reviewed and shared?*

Adapted from Marine and coastal enhancement projects in Scottish inshore waters - project assessment form (NatureScot)