

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

Evidence Base Note

Reference number: GN064

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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.

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1. 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). Each are outlined in Section 2.4 below.

Ecoengineering 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 eco-enhancements. Soft ecoengineering, such as beach nourishment or creation of intertidal saltmarsh, are not considered within this report as a primary ecoengineering approach for capital or maintenance schemes, but are discussed should individual projects or programmes be suitable for larger scale enhancement. For more information on Nature Based Solutions for Coastal Management see Section 6.

High-level decisions regarding the appropriateness and ecological value of hard versus soft / hybrid management approaches are outside the scope of this document. 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.

2. Diben y Nodyn Cyfarwyddyd

Diben y ddogfen hon yw cynnig gwybodaeth a thystiolaeth ynghylch buddion a gwerth am arian defnyddio gwelliannau ecolegol mewn strwythurau arfordirol. Mae deddfwriaeth a pholisïau amrywiol yn cefnogi defnyddio gwelliannau 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. Mae pob un wedi'i amlinellu yn Adran 2.4 isod.

Mae ecobeirianeg yng nghyd-destun yr adroddiad hwn yn cyfeirio at ddarparu neu addasu asedau arfordirol drwy ychwanegu neu addasu strwythurau caled er mwyn darparu gwelliannau ecolegol a chynyddu 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 is-lanwol bas, ac mae'n bosib bod eraill yn cael eu defnyddio o fewn rhannau llanwol afonydd neu mewn lleoliadau aberol ac afonol. Am y rheswm hwn, mae'r ddogfen hon yn canolbwyntio'n bennaf ar eco-welliannau rhynglanwol. Ni chaiff dulliau ecobeirianeg meddal, megis adfer traethau neu greu morfeydd heli rhynglanwol, eu hystyried yn yr adroddiad hwn fel rhai o'r prif ddulliau ecobeirianeg ar gyfer cynlluniau cyfalaf neu gynnal a chadw, ond fe'u trafodir rhag ofn y bydd prosiectau neu raglenni unigol yn addas ar gyfer gwelliannau ar raddfa fwy. I weld rhagor o wybodaeth am Atebion Seiliedig ar Natur ar gyfer Rheoli'r Arfordir gweler Adran 6.

Mae penderfyniadau lefel uchel ynghylch priodoldeb a gwerth ecolegol dulliau rheoli caled o gymharu â rhai meddal / hybrid y tu hwnt i gwmpas y ddogfen hon. Felly, dylid defnyddio'r ddogfen hon i gyrchu gwybodaeth pan 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 ddatgomisiynu strwythurau artiffisial arfordirol, a hoffai archwilio'r cyfleoedd i ddefnyddio gwelliannau.

Mae'n cynnig manylion ynghylch y wybodaeth, y prosesau a'r ffactorau perthnasol i'w hystyried, ac yn cyfeirio at rai o'r prif ffynonellau tystiolaeth i gefnogi gwneud penderfyniadau ar sail tystiolaeth.

3. Context

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.

In addition to their main purpose, artificial structures fulfil other functions to communities, people and the environment such as educational, amenity and habitat creation.

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.

Ecoengineering enhancements 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 pre-fabricated habitat units.

The materials used in structures can also be selected to promote biodiversity. This could include using natural rock similar to 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. Ecoengineering 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 ecoengineering 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. Nevertheless, 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 has led to increasing risk of flooding and erosion to people, homes and businesses. Across Wales, over 245,000 properties are at risk of flooding from rivers, the sea and surface water according to Flood Risk Assessment Wales, NRW (2019), with almost 400 properties also at risk from coastal erosion according to the National Coastal Erosion Risk Map (2012), under most likely scenario under SMP policies over next 100 years. Figure 1 illustrates climate change predictions for Wales by 2050 and 2080.

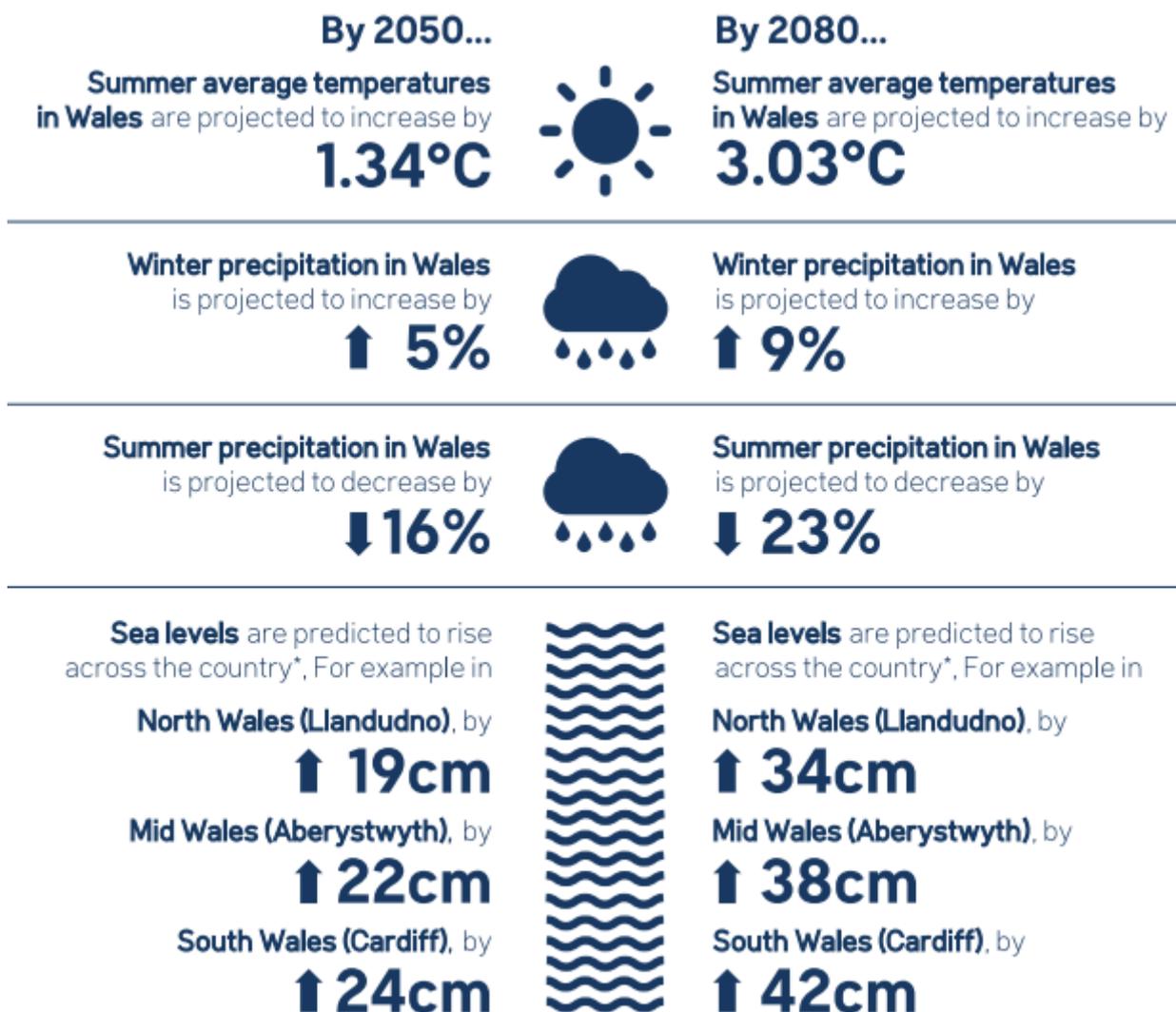


Figure 1 Climate change prediction by 2050 and 2080 taken from UK Climate Projections (UKCP18). Figure extracted from Historic Environment and Climate Changes in Wales. Sector Adaptation Plan, 2020.

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.

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”*.

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. As part of the Ecostructure project, a study is currently being undertaken to quantify the deficit in different habitat types, the results of this study are not available at the time of writing this note. A link/and or appropriate reference to the publication will be incorporated in due course.

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.

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 ecoengineering 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 ecoengineering. However, certain species may still benefit from coastal ecoengineering 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 ecoengineering solutions must take into account 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 ecoengineering 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 similar to 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 ecoengineering 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, ecoengineering 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 ecoengineering 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 zonations 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 ecoengineering 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, ecoengineering 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.

The size and shape of microhabitats also affects the type, size and number of organisms that can use them. Therefore, the size and shape of artificial habitats created as part of ecoengineering actions are also likely to affect biodiversity outcomes. Similarly, ecoengineering 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 ecoengineering 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](#). 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 ecoengineering 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

A number of legislative and policy drivers require and manage the deployment of coastal ecoengineering. Principle statutory instruments and key policy are listed below.

Key Legislative Drivers – Ecoengineering 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 – Ecoengineering 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.

- **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 ecoengineering 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 ecoengineering 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 ecoengineering 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. Consenting and Delivery Requirements

Consenting and Licensing – All Projects

Baseline Data – prior to deployment of coastal ecoengineering, 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 - deposits or removals (using land or marine equipment) below Mean High Water Springs (MHWS) require a marine licence from the NRW Marine Licensing Team (MLT). Coastal ecoengineering 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 ecoengineering techniques is outlined in Section 7. 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.

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 ecoengineering structures. In more complex circumstances, a full WFD Compliance Assessment may be required. Further advice is provided in NRW OGN72 [Complying with the Water Framework Directive Regulations 2017: how to assess and appraise projects and activities](#).

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 of 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 Operational Guidance Note 200 [Habitats Regulations Assessment of Projects](#) 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 eco-engineering 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 UK's 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/arch/> 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 ecoengineering 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.

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 next section 'Implementation and Delivery'). 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 eco-engineering 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 are also provided in Section 7.

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 ecoengineering 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 et 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 strengthens 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 as a result 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 (Salaudin M. et al., 2021).

However, Salaudin 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 ecoengineering 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 ecoengineering 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. A number of 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 bestpractice in providing enhancements and increasing resilience and ecosystem function on the Welsh coast.

Implementation and Delivery

As described above, a number of 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 ecoengineering 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.

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 7, 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 7, 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.

Most of the coastal / estuarine ecological enhancements implemented in the UK to date form part of prototype, pilot schemes or research projects with limited timeline and / or at small scale. Implementing those ecological enhancements at a greater scale, for example to an entire scheme, brings upscaling challenges. The upscaling challenges range from procurement constraints (as described above), cost, buildability, unknown hydraulic/environmental performance, influence on the structural integrity of the underlying asset, to ecological benefits which are difficult to quantify with sufficient confidence.

A [benthic habitat assessment](#) is recommended for each site to establish existing communities (constraints and opportunities), set realistic and measurable objectives and inform which ecoengineering 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.

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 7.3. Moreover, monitoring and evaluation for initial deployment of techniques will build the evidence-base 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 5.

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.

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).

5.Planning, Delivery and Maintaining Coastal Assets

5.1. Coastal Assets

This guidance note focuses on coastal and estuarine assets, some of which are outlined below.

Outfalls



Source: [Coldharbour outfall extension \(2018\) – South East Coastal Group \(se-coastalgroup.org.uk\)](#)

Open channels (tidal)



Source: [A bend in the river, Bridgend - geograph.org.uk - 1692133 - Bridgend - Wikipedia](#)

Walls including concrete and masonry walls



Source: [Sea Wall - Coastal Erosion Management, Criccieth, North Wa... | Flickr](#)

Embankments including concrete faced, gabions, rock armour and riprap engineered embankments.



Source: [River Tawe Swansea 2017 05 11 #28 | Gareth Lovering | Flickr](#)

Ramps and slipways



Source: [We walked along to the concrete access ramp which enables ... | Flickr](#)

Weirs



Source: [welsh weir - Bing](#)

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



Source: [Porthcawl town beach re-opens to the public after £3m improvements to sea defences - News from Wales](#)

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



Source: [Rock Groyne © N Chadwick cc-by-sa/2.0 :: Geograph Britain and Ireland](#)

Spillways



Source: [Llyn Brianne Spillway | turbostar171 | Flickr](#)

Bridge abutments



Source: [Blue Bridge \(Jubilee\) At Queensferry Deeside, Wales, UK. Queensferry is a town and electoral ward in Flintshire, Wales, lyi... | Photography, Bridge, Portrait photo \(pinterest.com\)](#)

5.2. Barriers to Implementation of Ecological Enhancements

A number of workshops and meetings were held with NRW and multiple stakeholders with the aim to identify the barriers to a wider implementation of ecological enhancements.

The stakeholders consulted in one-to-one engagement were: Welsh Government (Appraisals Team), Dŵr Cymru Welsh Water, Network Rail, Conwy Council, Bridgend Council, Gwynedd Council / YGC (Ymgynghoriaeth Gwynedd Consultancy) Pembrokeshire Council, Severn Estuary Coastal Group, Dyfed Archaeological Trust, Environment Agency (Coastal Adaptation Advisory).

Other stakeholders who attended workshops were: National Trust, JBA, Amey and Milford Haven Port Authority.

The barriers identified as most relevant have been grouped in three categories: Resources – People and Budget; Upskilling and Knowledge Sharing; and Organisation and Processes.

Resources - People and Budget

- Lack of a dedicated person/team and budget to undertake delivery and carry out monitoring, which is key to measure success, record learning and to build on the evidence base of ecological enhancements.
- Funds not available/allocated to facilitate community engagement to understand how the public perceives ecological enhancements.
- Organisations generally have limited resources to dedicate to this niche subject.
- Ecological enhancements often are outside typical background of officers and engineers who deal with flood defences and coastal structures namely in activities such as design, inspection and maintenance.
- Lack of qualifications due to specificities of biodiversity in the marine and intertidal environment. Person undertaking monitoring and reporting or advising on mitigation measures from a regulatory point of view needs adequate qualification and/or training.
- Perceived perception from communities of public spending on ecological enhancements vs improvement of flood risk.

Upskilling and Knowledge Sharing

- Lack of awareness of key policy and legislative drivers to incorporate ecological enhancements to existing structures, particularly as part of maintenance and repair works.
- Lack of knowledge and experience on the following aspects in relation to ecological enhancements:
 - Effects on structural integrity
 - Aesthetic effects in highly visible places
 - Public safety (e.g. slippery surfaces, attachments to structures falling down)
 - Maintenance (e.g. structure may collect marine litter)
 - How to evaluate success
 - Demonstrate and capture value for money by measuring benefits
 - Matching intertidal habitats with the appropriate enhancements

- Volume and extent of the enhancements to achieve the ecological goals
- How to select the right intervention
- Impact to standard of protection
- Cost
- Not promoting and advertising the wider benefits of implementing ecological enhancements.
- Difficulty in bridging the gap between research in academia on small scale interventions to large scale prototype implementation.
- Manufacturers still building track record.
- Lack of information sharing within the organisation or between organisations but also with the general public.
- Lack of understanding from applicants and scheme proponents of what is required to demonstrate the impact of implementing ecological enhancements on the underlying infrastructure/asset.

Organisation and Processes

- Lack of understanding of the processes and teams involved in taking ecological enhancements from inception to deployment, in particular, as part of maintenance and repair works.
- Lack of a formalised process to incorporate enhancements and improvements as part of planning maintenance and repair works.
- Opportunities for ecological enhancements are not being considered from the project inception/early stages of the design as they tend to focus on main project elements and their functional requirements which leaves little room for introducing or influencing decisions at a later stage of the project.
- Community engagement is not being considered from the outset of the project, missing their buy in and potentially valuable local experience. There is also evidence that lack of community engagement can result in opposition to the interventions and vandalism.
- There isn't a clear understanding of who to consult in the regulatory space about ecological enhancements and responsibilities related to ongoing monitoring.
- Lack of aligned industry targets or goals which can support the specification of type and quantity/extent of enhancement or mitigation required.
- General lack of information to be able to undertake a cost/benefit analysis with sufficient level of confidence.
- Legislative framework and remit that some organisations need to comply with limits the scope for ecological enhancement interventions.
- Time/cost required to obtain licences (e.g. marine licence Band 2) for small scale interventions can be disproportional to magnitude of the works and the cost of the enhancements.

5.3. Actions for Effective Implementation of Ecological Enhancements

In consultation with NRW and other stakeholders, some actions were identified to overcome the barriers discussed in Section 4.2 which are presented below:

Resources - People and Budget

- Increased budget to support implementation, from inception to deployment and maintenance, particularly for retrofitting and remedial works. There are funding mechanisms currently available to support deployment such as Welsh Government Water Capital Fund. Other funding opportunities can also be considered under Flood & Coastal Erosion Risk Management, as highlighted in the National Strategy for FCERM (2020) paragraphs 37, 307, 242 and 278.
- Additional resources (people) to support with expert input into the implementation decision, from inception to deployment.
- Appoint a person/team whose remit is on-going monitoring and maintenance of ecological enhancements. Suitable budget and people would need to be allocated to those teams including allowance for training, if required. Ad-hoc or monitoring in a non-structured way will still be useful and helpful but a systematic approach is preferred to provide greater consistency and relevance to findings.
- Where budgets and/or resource for monitoring are constrained, there are opportunities to work with local universities and volunteer conservation organisations to support the activity, or request that suppliers incorporate the monitoring into their costs. Involving communities, local volunteers through citizen-science type projects could potentially also help with resourcing for monitoring, increased awareness, wider acceptance and less vandalism.
- Target ecological enhancements through organisation's own programme of installations on existing assets (where retrofitting is appropriate). A short-term targeted programme could increase confidence and experience for larger implementation in the future.
- NRW should consider reviewing/amending Marine Licence Bands, in particular Band 1, to allow more streamlined process for small scale ecological interventions.
- Allow in funding applications time and resources for knowledge transfer e.g. training between experts such as NRW, Consultants, other organisations and the Local Authority or asset owner.
- Allow in funding applications time and resources for monitoring and reporting. Publishing findings will improve future evidence-based decisions and will improve databases such as the [Conservation Evidence Actions](#) and the [OMReg](#) database.
- Recognise the need for input from material specialists e.g. concrete or formliner specialists to work with main contractors due to specifics of eco-enhancements. With eco-enhancements made of concrete, specialists will have expertise on concrete mixes, moulds, use of rubber, de-moulding etc.
- Consider including greening grey infrastructure as wider benefits in Business Cases.

Upskilling and Knowledge Sharing

- Understand what is included in this guidance note. A training toolbox is available to disseminate the content of this note (see Appendix B).
- Organise call off arrangements, 'technical surgeries', to provide ad-hoc advice and support as/when needed. The technical surgeries could include specialists within NRW and consultants.
- Publicise and celebrate those projects where ecological enhancements are being or have been implemented. Identify metrics to quantify enhancement benefits.
- Generate lessons learned documents with a specific focus on ecological enhancements to build evidence base. Lessons learned should include, but not be limited to, observed ecological and wider benefits, challenges overcome from inception to delivery, maintenance and asset management requirements, suppliers

involved. Lessons learned documents could be disseminated in lunch time talks across different teams and organisations.

- Name a champion in each organisation or team to sign up to newsletters from providers and research to keep up to date on the latest on ecological enhancements and cascade to others.
- On relatively large schemes, consider including interpretation boards on the promenade or coastal path to provide information and raise awareness on biodiversity and the ecological enhancements. This can also reduce vandalism and need for repairs/reinstatement.
- Make the most of existing resources and published guidance in devising a monitoring strategy – see further details in Section 7.3.

Organisation and Processes

- Include ecological enhancements as an item in the agenda when discussing the wider project benefits with stakeholders.
- Join up opportunities with wider work being done on nature-based solutions. For example, there is a programme that is looking at developing the opportunities for habitat restoration. This is reported in NRW Evidence Report 554 Restoring marine and coastal habitats in Wales: identifying spatial opportunities and benefits.
- Consult early on with specialists across NRW to identify opportunities for ecological enhancements.
- An opportunity for wider implementation of ecological enhancements can be to tag to routine maintenance e.g. repointing of walls and monitoring can coincide with yearly /regular asset inspections.
- Include ecological enhancement interventions into (capital) project wide processes where benefits can be obtained from little additional effort e.g. within a marine licence application or post construction monitoring.

6. Conservation Evidence Synopsis

What is the Conservation Evidence Project?

[Conservation Evidence Project](#) was set up to summarise the documented evidence for the effectiveness of conservation actions and is designed to support decision making about how to maintain and restore biodiversity.

It contains the following range of resources: synopsis developed by conservationists and researchers in partnership with an international advisory board; a [database of summaries](#) of previously published scientific papers and reports; [What Works in Conservation](#) which provides expert assessments of the documented evidence; and an [online open access journal](#).

Synopsis Enhancing the Biodiversity of Marine Artificial Structures

The synopsis Enhancing the Biodiversity of Marine Artificial Structures (<https://www.conservationevidence.com/synopsis/pdf/35>) 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.

Appendix 2 in the synopsis should be used to search for information relevant to your work. The Appendix outlines a list of intervention titles, definitions, and scale of interventions. To assess the applicability of the interventions it is recommended that you address the following questions:

- 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?

7. Nature Based Solutions for Coastal Management

NRW published in 2022 an overview of [nature-based solutions for coastal management](#), centralising currently available resources and literature. The following subjects are addressed:

1. What are nature-based solutions?
2. Shoreline Management Plans
3. Terms for nature-based solutions
4. Green-grey infrastructure
5. Blue-green infrastructure
6. Beach nourishment
7. Sand dune management
8. Saltmarsh and mudflat management
9. Shingle management
10. Scientific 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.

Nature-based solutions for coastal management include enhancing manmade structures with ecological features and enhancing natural habitats or landscapes.

The NRW nature-based solutions tool Section 4 Green-grey infrastructure is the subject of more detailed assessment in the current Guidance Note.

Sections 5 to 9 are complementary to the current Guidance Note and refer to the use of existing or enhanced natural landscapes (saltmarsh, sand dunes, shingle coastlines and wetlands) to increase resilience to climate impacts.

For each nature-based solution, a description in the context of coastal management is followed by references to useful publications and a summary of case studies. This can be used as a starting point to understand what potential alternatives are suitable for specific sites and can support evidence-based decision making.

Additional resources can be found in the NRW nature-based solutions tool:

- [OMRegdatabase](#). Compiles completed coastal habitat creation schemes and adaptation projects including outside the UK. Adding to the database is free and should be promoted.
- [NRW Evidence Report 554: Restoring marine and coastal habitats in Wales: identifying spatial opportunities and benefits](#). 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.
- [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.

8. Ecological Enhancements

8.1. Stepped Approach

A stepped approach to assist with deciding which ecological intervention is selected is proposed below.

Every location is different – a bespoke solution for the structure and environmental context in question is required. Please refer to Section 2.3 on how the environmental context is likely to influence biodiversity outcomes.

Step 1

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.

<p>Ecology</p> <ul style="list-style-type: none"> • Native species biodiversity • Habitat complexity • Invasive species management • Supporting protected site objectives • Promoting specific target species • Mimicking natural rocky habitats/biodiversity 	<p>Environmental</p> <ul style="list-style-type: none"> • Water quality • Carbon sequestration • Biofiltration 	<p>Economic</p> <ul style="list-style-type: none"> • Job creation • Business opportunity • Shore protection insurability
<p>Engineering</p> <ul style="list-style-type: none"> • Energy attenuation • Shoreline stabilisation • Structural integrity 	<p>Social</p> <ul style="list-style-type: none"> • Aesthetics • Tourism and recreation • Education 	<p>Governance and policy</p> <ul style="list-style-type: none"> • Hazard mitigation • Upscale use of ecological enhancements

Step 2

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?
- How difficult is access for implementation, monitoring and maintenance?

Step 3

Observe the **existing habitats** on site and in the vicinity (refer to the [Benthic habitat assessment guidance](#)). 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?

Step 4

Observe current **environmental conditions** including:

- Wind exposure.
- Wave and current exposure – 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.
- Surrounding habitat.
- Distance to natural rocky habitat for source supply.
- Predation potential.

Step 5

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

- Exposure to anthropogenic disturbance: public access, navigation, outfalls, foraging, maintenance, trampling, artificial light at night, etc.

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

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 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:

<p>Step 1 – High level objective: promote colonisation of general sea life on a plain vertical seawall</p>	<p>Step 7 – Refined objective:</p> <p>Promote colonisation of certain species of algae and limpets that thrive in intertidal environment with low wave exposure.</p> <p>Create X no. of water retention features because in a location nearby it was successful and can be used as a control site.</p> <p>Place new features at a certain level within the tidal range in an accessible location to allow for maintenance and monitoring.</p> <p>Organise community engagement session to gather support and raise awareness.</p>
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Step 8

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 1.

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 ecoengineering 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 \(2021\)](#), which presents the summary of evidence of the effects of different interventions, could assist with this assessment. 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 2.

Table 1: 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)
• 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 2: 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**.

Intertidal interventions

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	<i>Tubeworms*</i>	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

Subtidal interventions

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	<i>Tubeworms*</i>	Fish
Texture	positive	negative	positive	(non-significant)
Crevice	positive	positive	non-significant	non-significant
Pit	positive	(positive)	non-significant	non-significant
Rock pools	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 ≤ 1 mm
- Crevice – intertidal or subtidal depressions with a length to width ratio $> 3:1$, and depth > 1 mm
- Pit – intertidal or subtidal depressions with a length to width ratio $< 3:1$ and depth of > 1 mm 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 ≥ 5 cm depth

Step 9

- 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, the deficit of different habitats type between structures and natural intertidal reefs have been quantified. This will be a useful resource for deciding how much of a specific habitat intervention would be needed to mimic natural habitats. The results of this study are not available at the moment of writing this note. A link/and or appropriate reference to the publication will be incorporated in due course.

- 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 3. The likely applicability of each installation technique for different assets is presented in Table 4.

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 3: 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)
• Cut-in (to create a cavity from the surface)
• Bolt-on (to attach to the asset using bolts or anchors)

Table 4: 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 10

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 5 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.

Table 5 Products from specialist suppliers. – This is a list of products that could be suitable for NRW assets. Other options/alternatives may be available.

<p>Vertipools www.artecology.space</p>		<p><u>Intervention:</u></p> <ul style="list-style-type: none"> • Create rock pools <p><u>Installation technique:</u></p> <ul style="list-style-type: none"> • Bolt-on
<p>BIOBLOCK</p>		<p><u>Intervention:</u></p> <ul style="list-style-type: none"> • Create rock pools • Create pit habitats • Create crevice habitats <p><u>Installation technique:</u></p> <ul style="list-style-type: none"> • Drop-in prefabricated units
<p>EConcrete rock pools https://econcretetech.com/</p>		<p><u>Intervention:</u></p> <ul style="list-style-type: none"> • Create rock pools • Texture surfaces <p><u>Installation technique:</u></p> <ul style="list-style-type: none"> • Drop-in prefabricated units

<p>EConcrete® seawall panels</p> <p>https://econcretetech.com/</p>		<p><u>Intervention:</u></p> <ul style="list-style-type: none"> • Create rock pools • Create hole habitats • Create ledges or ridges <p><u>Installation technique:</u></p> <ul style="list-style-type: none"> • Bolt-on
<p>EConcrete® piles and jackets</p> <p>https://econcretetech.com/</p>		<p><u>Intervention:</u></p> <ul style="list-style-type: none"> • Use environmentally sensitive materials • Textured surfaces <p><u>Installation technique:</u></p> <ul style="list-style-type: none"> • Cast-in
<p>Living Seawall panels</p> <p>Living Seawalls — REEF DESIGN LAB</p>		<p><u>Intervention:</u></p> <ul style="list-style-type: none"> • Use environmentally sensitive materials • Create rock pools • Create hole habitats • Create crevice habitats <p><u>Installation technique:</u></p> <ul style="list-style-type: none"> • Bolt-on
<p>Sea-Hive</p> <p>www.cubexindustries.co.uk/</p>		<p><u>Intervention:</u></p> <ul style="list-style-type: none"> • Use environmentally sensitive Ultra High-Performance Concrete (UHPC) • Create hole habitats • Create crevice habitats • Create textured surfaces <p><u>Installation technique:</u></p> <ul style="list-style-type: none"> • Bolt-on

Step 11

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 ecoengineering may not be positive.
- 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 12

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).

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 6 presents a qualitative comparison between different techniques that can be applied to two groups of structures: rock structures and vertical (or near vertical) concrete faced structures. Table 6 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 6, 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 8 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 eco-enhancements covered in this note plus others not covered here.

Table 6: Cost value assessment for different techniques when used in rock structures and vertical concrete faced structures. 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.

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
Bolt-on precast tiles and panels (with several habitat interventions)	medium	medium	medium	medium

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

8.2. Techniques and examples of implementation

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.

(A) Pits [Source: Hall et al., 2018]



(B) Grooves [Source: Hall et al., 2018]



Figure 2 Technique 1 Drill-in pits, grooves and crevices

Effectiveness: benefits assessment

- 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.

Policy – 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.

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 actually 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)

Timescales

- Likely consenting route: drilling (removal activity) – likely no marine licence when undertaken on an artificial structure; confirm with NRW MLT in advance. Any sacrificial layer would need to be integrated into the design or would require a marine licence to deploy post-development.

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).

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).

(A) Cores [Source: Firth et al.,2014]

(B) drill-cored rock pools [Source: Evans et al., 2016]



Figure 3 Technique 2 Cut-in rockpools

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

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

Timescales

- 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 4 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 reset 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.

Timescales

- 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.
- (C) Seawall / riverwall

(A) EConcrete® piles and jackets



(B) Outfall pipe on Hannafore beach in West Looe, Cornwall



(C) Seawall/Riverwall at Portsea Island [Source: Coastal Partners <https://coastalpartners.org.uk/>]



Figure 5 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.

Timescales

- 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.

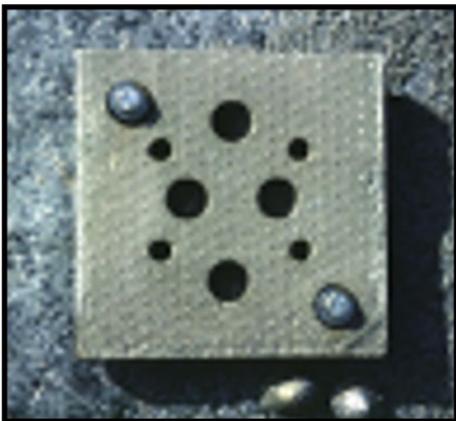
Technique 5 – Bolt-on precast panels and tiles

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).



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



Living Seawall panels



ECONcrete® panels in a seawall

Figure 6 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.

Timescales

- 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.
- Living Seawall panels have a typical design life of 20 years.

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 m² 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.

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 7 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 none 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).

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.

Timescales

- 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.
- After 3 years, they increased species diversity and attached mobile fauna including crabs and fish.

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 8 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.

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.

Timescales

- 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.
- Test completed over 14 months. Significant peak in vegetation during spring/summer months. Peak cover after 5-9 months (from January).

Technique 8 – Drop-in prefabricated units

Description

Precast concrete units which mimic one or multiple habitat enhancements such as 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 [Source: Naylor et al., 2017]



(B) Econcrete Tidal Pool [Source: Coastal Partners <https://coastalpartners.org.uk/>]



Figure 9 Technique 8 – Drop-in prefabricated units

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.

Maintenance and asset management considerations

- They can be installed during construction or retrospectively.
- BIOBLOCK should last >10 years (Naylor et 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 approximately £2,000 for mould, 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.

Timescales

- 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.
- 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).

Technique 9 – Miscellaneous

Description

A number of 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/helppourkelp>
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.

Timescales

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.

8.3. Monitoring and measuring success

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

- Undertaking 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 Note GN030](#), 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>. In the event that INNS are identified, it should be reported to NRW and a Marine Invasive Species Management Plan prepared.

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Appendix A – Case Studies

Technique 1 - Pits, Grooves and Crevices

From Firth et al. (2014) – Creation of artificial pits on Plymouth Breakwater, England

Plymouth breakwater, a 1.56 km detached structure, is ca. 3 m above chart datum and extends to ca. 10 m into the subtidal. The seaward side is protected by cast concrete wave-breaker units which 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 No. control quadrats of 100 × 100 cm with no pits were also monitored.

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 $0.05/3=0.016$.

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.

From Naylor, LA., et al, (2017) and Hall et al, (2018)- Pits and groves testing at Runswick Bay and Poole Bay, UK.

Pits and groves habitat features were tested at Runswick Bay and Poole Bay. Both sites are moderately exposed sandy shores. The aim was to test the efficacy of increased surface heterogeneity and retrofitted water retaining features in improving ecosystem enhancements of rock armour.

Granite and limestone rock armour were retrofitted with habitat features by drilling (arrays of 4 holes, 16 mm diameter x 20 mm deep) and scoring the rock armour with petrol saw/angle grinder (to mimic mining artefacts). Score marks were 2 mm x 600 mm x 10 mm deep above and below a central 1 mm x 600 mm long by 20 mm deep groove. The coarser middle grooves were chiselled out to create rough surface texture on the base and sides.

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

Both sites were monitored for 12 months where 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. Other ecosystem services were not measured as part of this study.

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.

Technique 2 - Artificial Rock Pools

From Firth et al. (2014) – The in-filling of cores to create artificial rock pools at Penrhyn Bay, Wales

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. The experiment ended after nine months in March 2013 when pools and adjacent emergent substrata of comparable area were visually inspected and all epibiota identified.

Only five cores retained water sufficiently to function as rock 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.

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 3 - Precast Habitat Enhancement Units

From Firth et al. (2014) and Naylor et al. (2017) – Deployment of precast prototype BIOBLOCK at Colwyn Bay, Wales.

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. 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. 12No. 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 10 BIOBLOCK [Source: Naylor et al. (2017)]

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

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. Thus, 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.

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

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.

It must be noted that this was a prototype demonstration project and that a fully replicated experiment followed by long-term, sustained monitoring (Hawkins et al., 2013a, 2013b) is essential to accurately assess patterns of distribution and abundance in relation to the different habitat types.

BIOBLOCKs deployed at Teats Hill, Plymouth, UK

Five BIOBLOCKs have been 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.

They were designed to raise awareness of the potential benefits of artificial reefs in the marine environment. The units have been specifically positioned by the slipways at Teats Hill so they can be observed by the public.

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.

See further information on the University of Plymouth [webpage](#).



Figure 11 BIOBLOCK being lifted into place [Source: <https://www.plymouth.ac.uk/news/bioblocks-show-how-coastal-designs-could-benefit-marine-life>]

Technique 4 – Precast Tiles / Panels

Living Seawall Panels at Sydney Harbour, Sydney, Australia

‘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.

See further information on the North Sydney Council [webpage](#).



Figure 12 Living Seawalls at Sydney Harbours. [Source:<https://www.sustainabilityhackers.com/living-seawalls-to-bring-new-life-to-rushcutters-bay/>]

Tiles retrofitted to Mumbles Sea-Hive Project, The Mumbles, Wales

Mumbles Sea-Hive is a Swansea University SEACAMS2 project in collaboration with Swansea Council and Amey plc. SEACAMS2 is part-funded by the European Regional Development Fund (ERDF) through the Welsh Government. It is 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).

135No. hexagonal tiles are being installed along the Mumbles sea defences. Each tile is around 50cm wide, and they have a variety of patterns. Some mimic natural rock surfaces, others have geometric patterns, some reflect the history of the local oyster industry.

The aim is to test which patterns provide the best home for local sealife such as seaweeds, barnacles and other creatures. The most effective patterns may be used on parts of an updated sea defence system now being planned for Mumbles.



Figure 13 Mumbles Sea-Hive tiles – image courtesy of Ruth Callaway from Swansea University

From Borsje et al. (2011) – Textured and structured tiles retrofitted to breakwater concrete blocks, North Sea Channel at IJmuiden, The Netherlands.

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.

Analysis of the photographs taken of the sections on the tiles showed that the 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. Moreover, 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 lead to better settlement and growth conditions for algae and macrobenthos.

Technique 5 - Vertical Pools

From Hall et al. (2019) – Vertipools at Bouldnor Beach, Isle of Wight, UK

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.

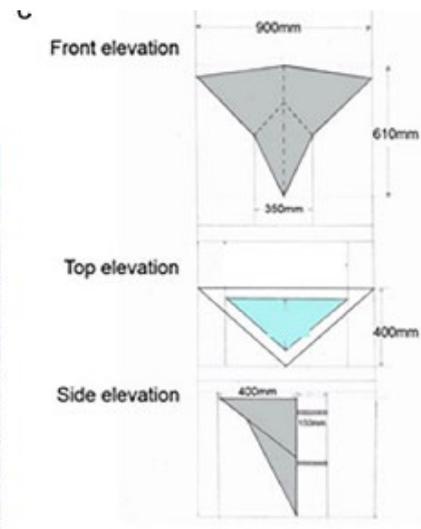


Figure 14 Location of the Vertipools on the seawall (left) and dimensions of the Vertipools (right) [Source: From Hall et al. (2019)]

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.

All of 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.

Technique 6 - Textured Concrete

From Naylor et al. (2017) – Eco-enhanced stormwater outfall at Hannafore beach in West Looe, Cornwall.

Test tiles for a pre-cast concrete unit were retrofitted to a stormwater outfall at Hannafore beach, Cornwall.

The tiles were specifically designed to create suitable grooves and water-holding habitat for mobile species along with a clear path for people to walk along –so that habitat and human activity could be catered for on the stormwater outfall.



Figure 15 Eco-enhanced stormwater outfall at Hannafore beach

A three-fold increase in animal and double the algal species diversity was found on the grooved tile compared to the ordinary smooth concrete surface in less than 6 months. Animal abundance increased 30 fold on the wave tile compared to the business as usual, ordinary smooth concrete surface.

In a survey of 25 respondents, 64% of people preferred the wave tile design compared to business-as-usual; they felt it was likely to provide more ecological value than the business-as-usual smooth concrete alternative. They also used the outfall for walking and launching kayaks.

The only additional cost for future applications would be design and production of textured formwork during the construction phase. For this prototype, the cost of design, production and deployment of test tiles was approximately £2,000 (~£1,000/m²).

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.

From Perkol-Finkel and Sella (2015) – Ecological pile encasement at Brooklyn bridge Park, NY, USA.

A number of 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 18No. 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. The ecological jackets provided all the functional and structural support required from a standard concrete encasement, yet with biological and ecological value.

All of 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.

The ecological jackets enhanced the recruitment of marine organisms, creating a richer and more diverse habitat compared to the control fibreglass jackets that offer very limited habitat value. Species richness on the enhanced jackets was double that found on the control jackets. The majority 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.

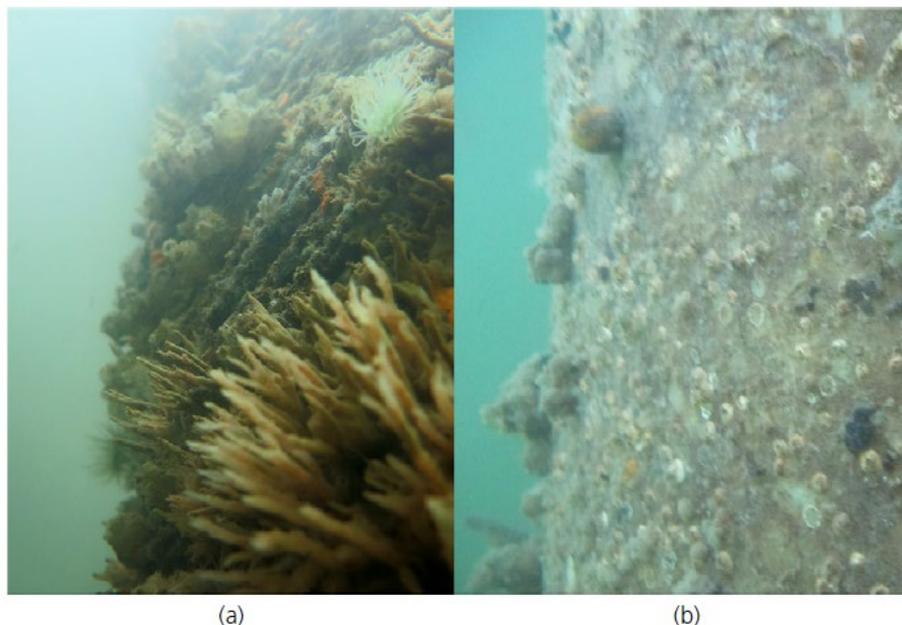


Figure 16 (a) ecological jackets and (b) control - fiberglass jacket. Both are 14 months post-deployment.

Technique 7 - Green Wall Modules

From Francis et al.(2015) – Green Wall Modules along the River Thames, London, UK

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, with the exception of one, where the wall sloped at an approximate 45° angle.

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.

Overall, vegetation establishment of the wall modules was disappointing for the sites with vertical wall modules. Only the site with wall modules installed at 45° 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 this trend is 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 as long as they did not make the walls appear untidy or neglected.

Appendix C – Examples of ecological enhancements

Artecology

Example of vertipools

Model: Bouldnor Vertipool
Volume: 10Ltrs approx
Weight: 75kg approx

Model: Gibraltar Vertipool
Volume: 10Ltrs approx
Weight: approx 50 kg

Model: Sandown Vertipool
Volume: 1.5Ltr approx
Weight: 8kg approx

M16 stainless steel threaded bar fixings
4x 60mm lengths.
Resin fixed into the concrete wall.
Stainless steel nyloc nuts to fix Vertipool in place.

Example of MudFlats

Artecology MudFlats™

HIGH-RISE SOFT SEDIMENT INTERTIDAL HABITAT SYSTEM FOR SHEET PILE.

		Per Meter Wall				Weight	
Active width W, mm	Height H, mm	Plate thickness mm	Elastic section modulus cm ³	Plastic section modulus cm ³	Coating area cm ² /m	Volume m ³	kg/m
700	500.2	12.1	3788	4262	161.16	2.38	94.984
		12.2					180.7
							126.5

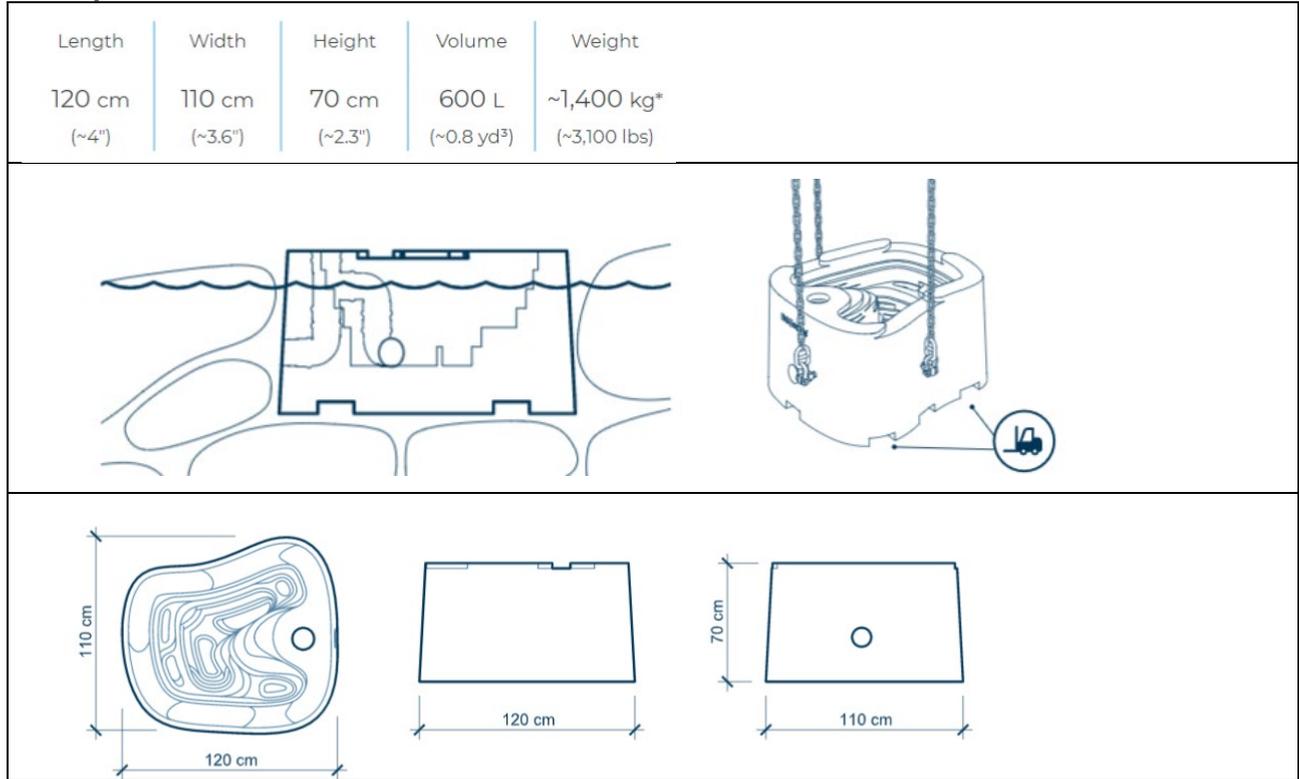
CubeX

Example of Mumbles Sea Hive panels

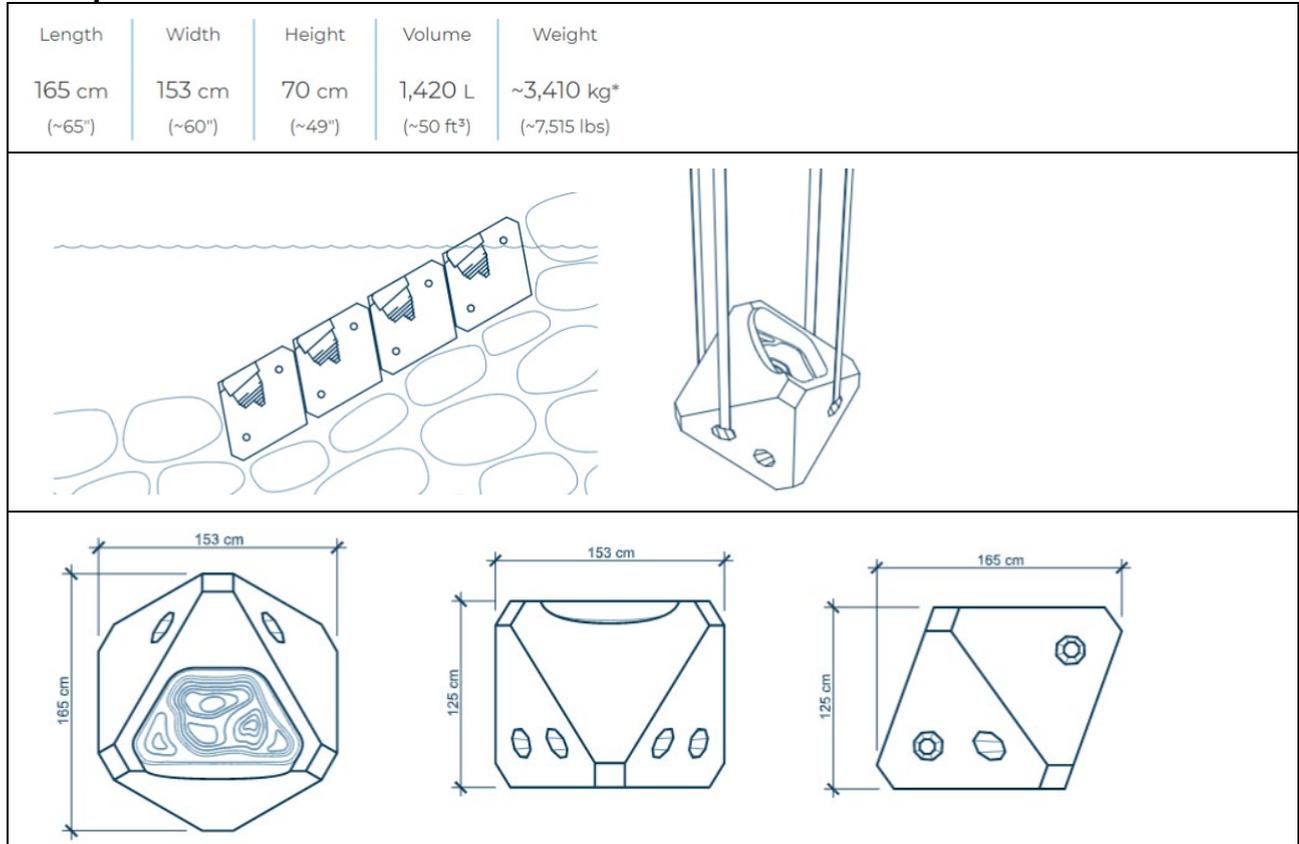


Econcrete

Example of Tide Pool

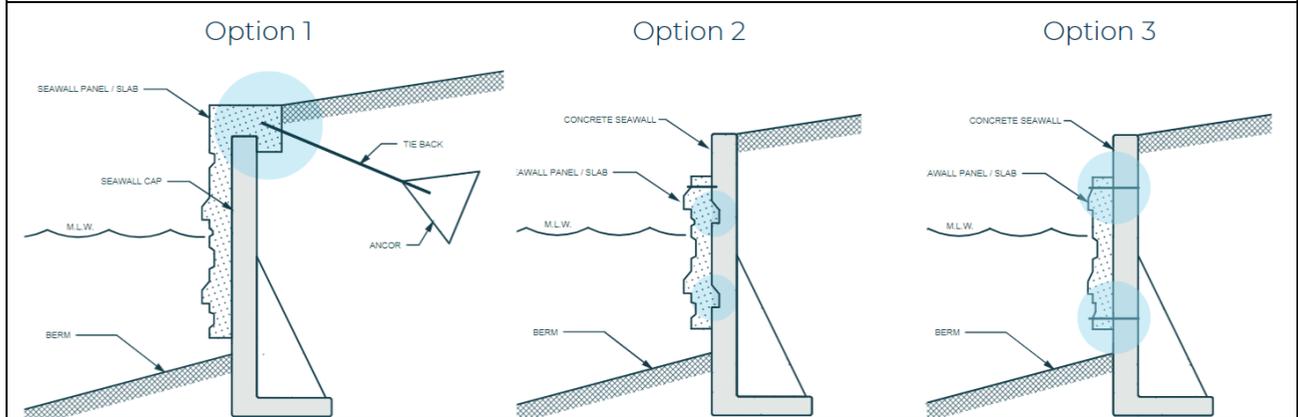
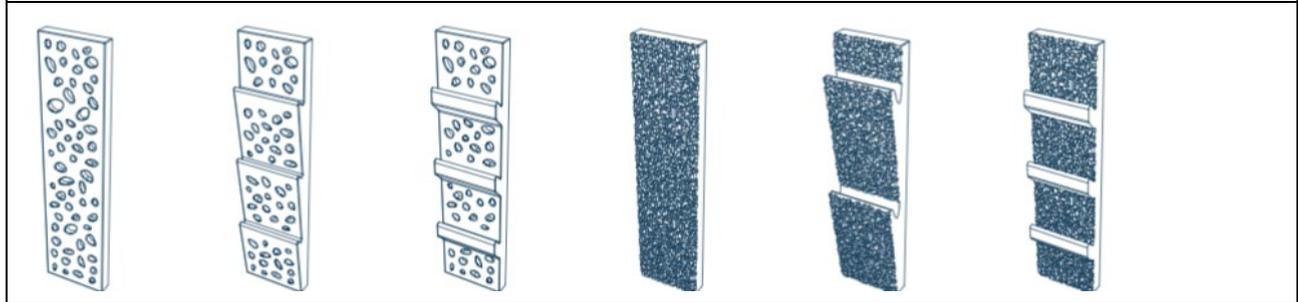


Example of Coastalock



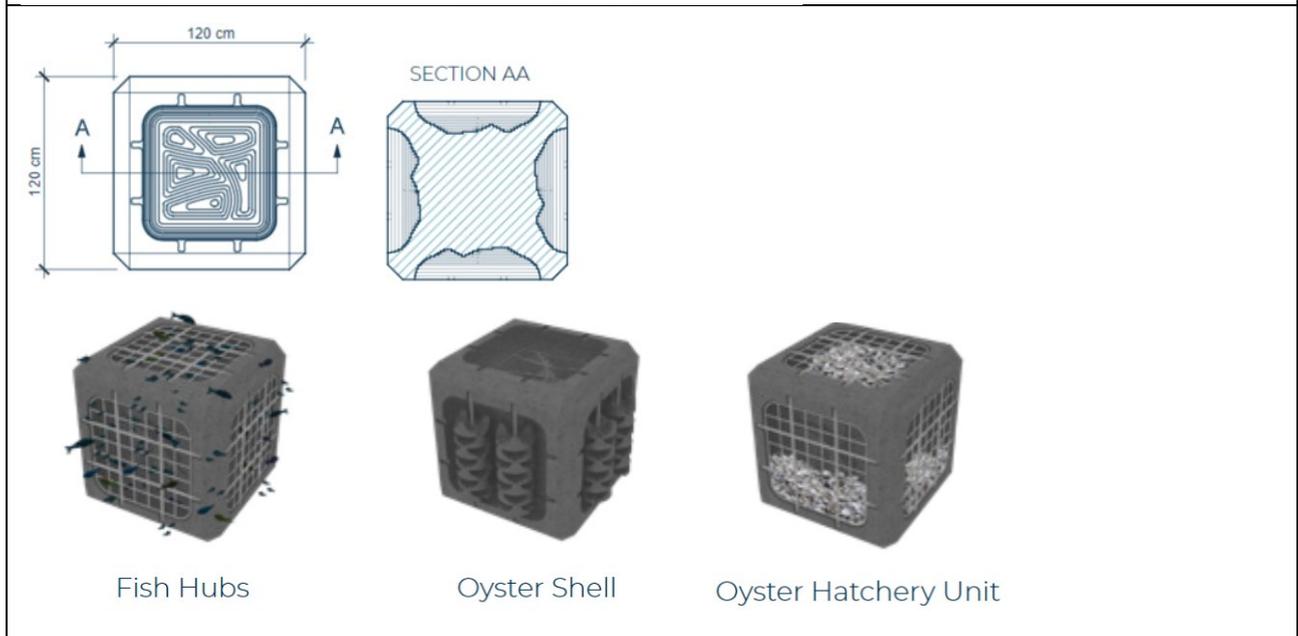
Example of Sea Wall Panels

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)

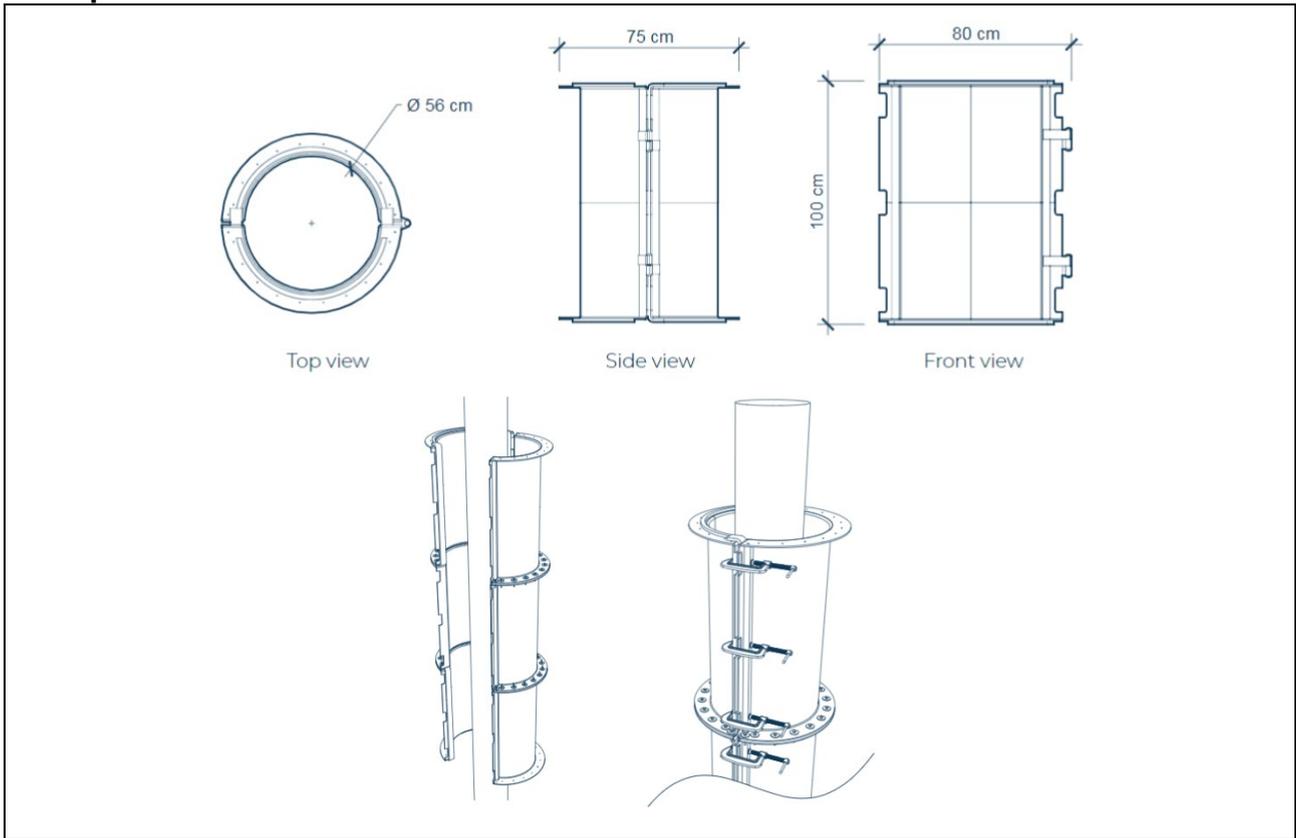


Example of Armor Blocks

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)

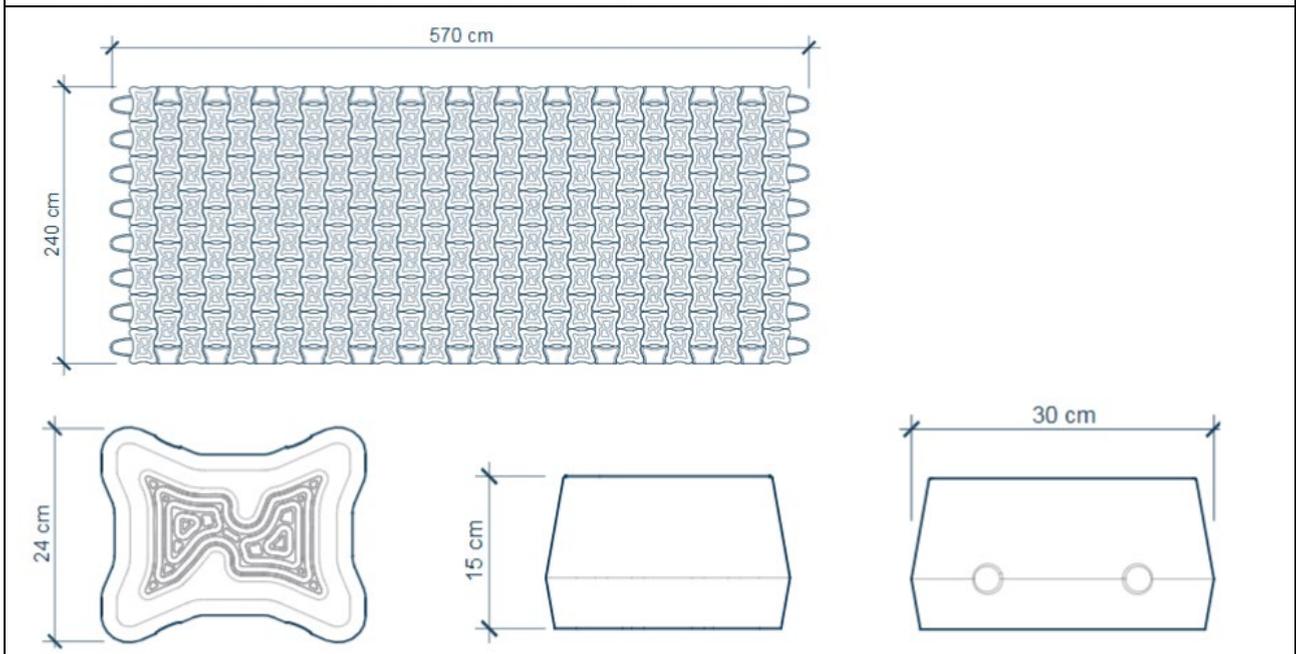


Example of Pile Jackets

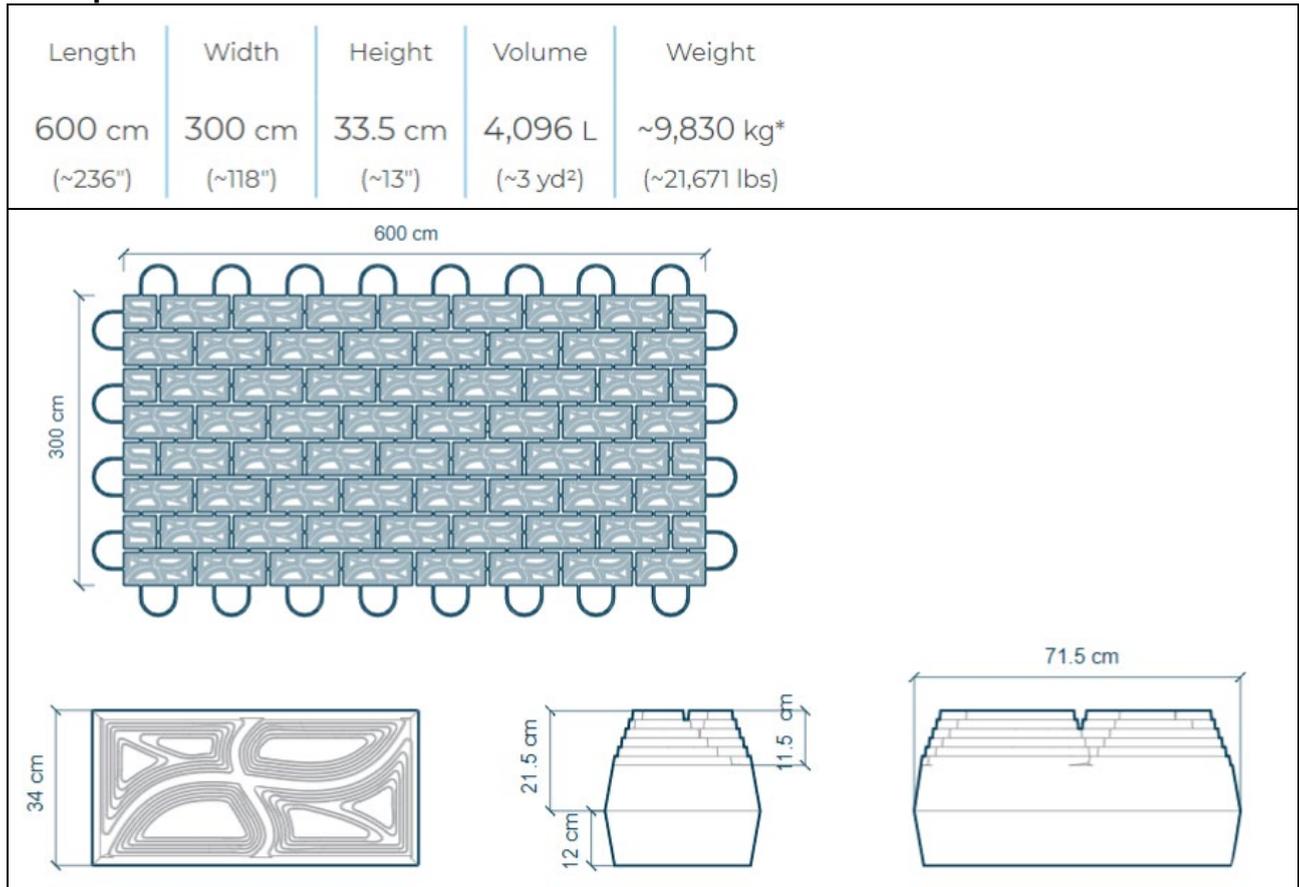


Example of Articulated Concrete Block Mattress

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

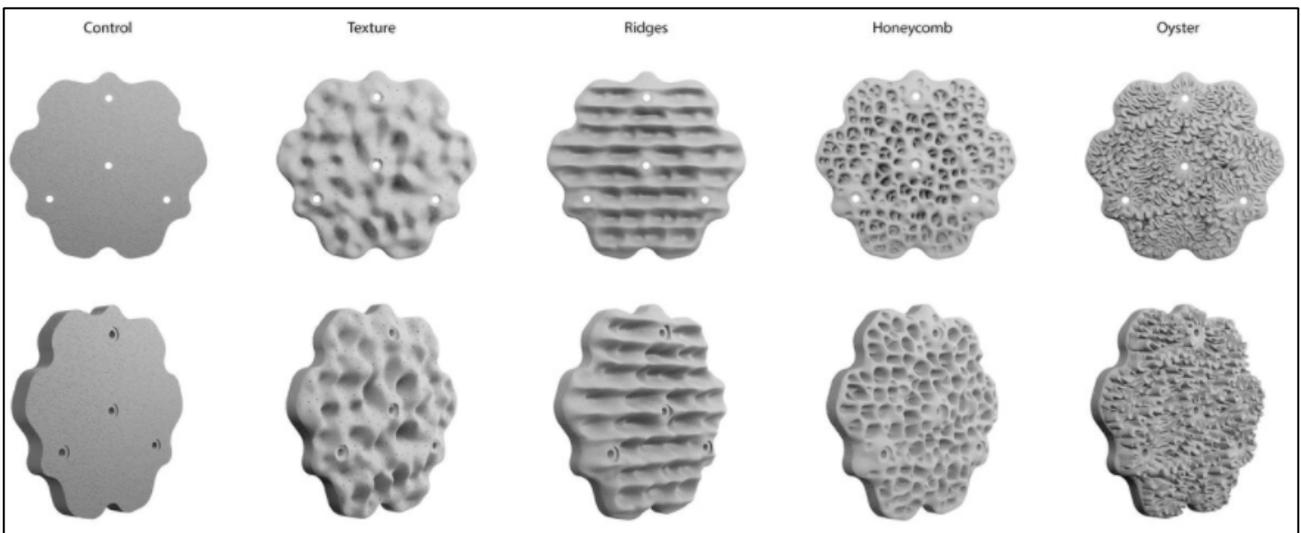
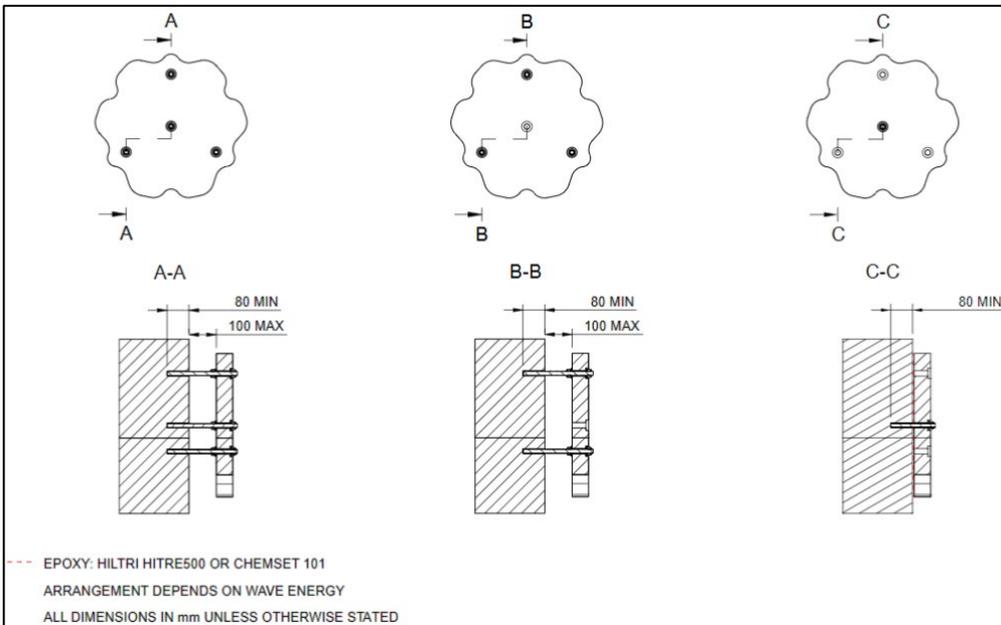
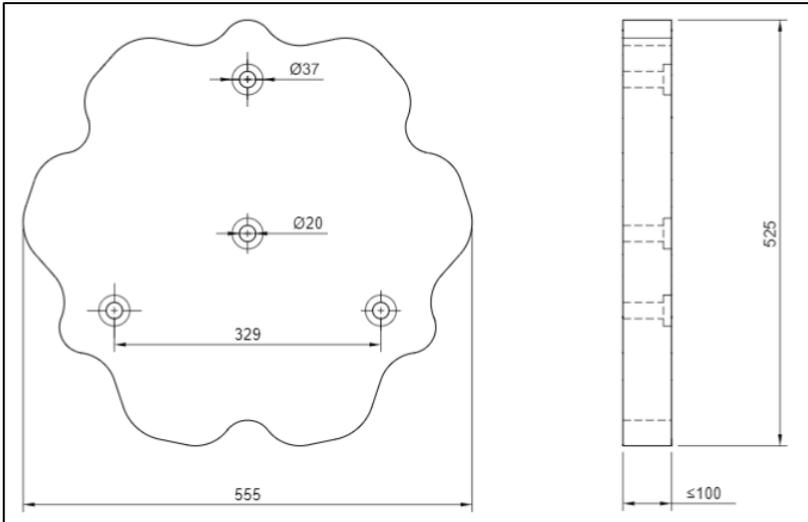


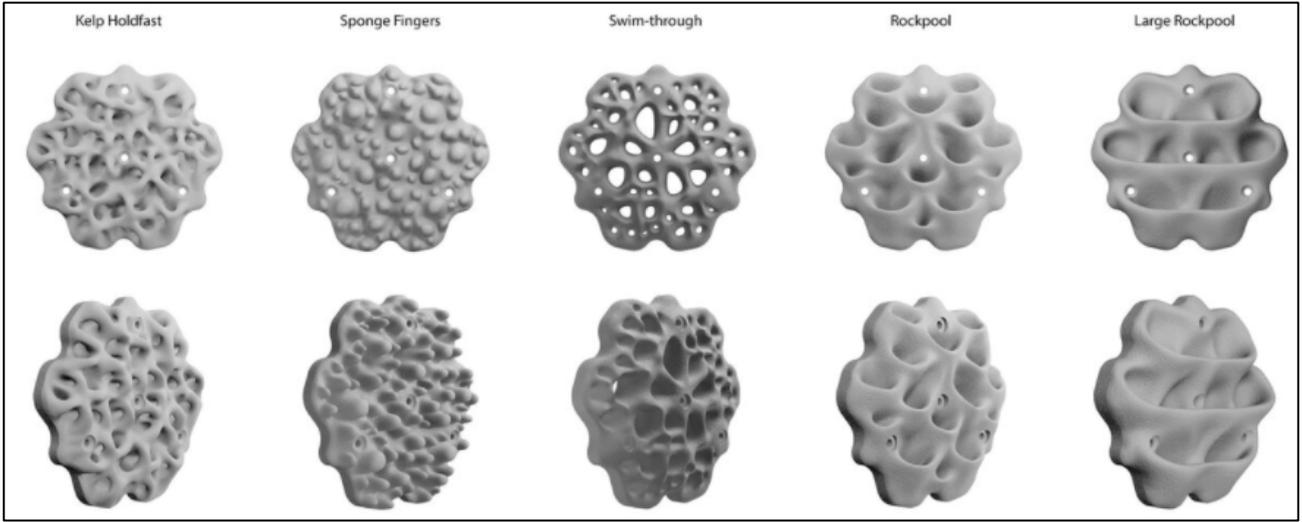
Example of Marine Mattress Wet Cast



Living Seawalls

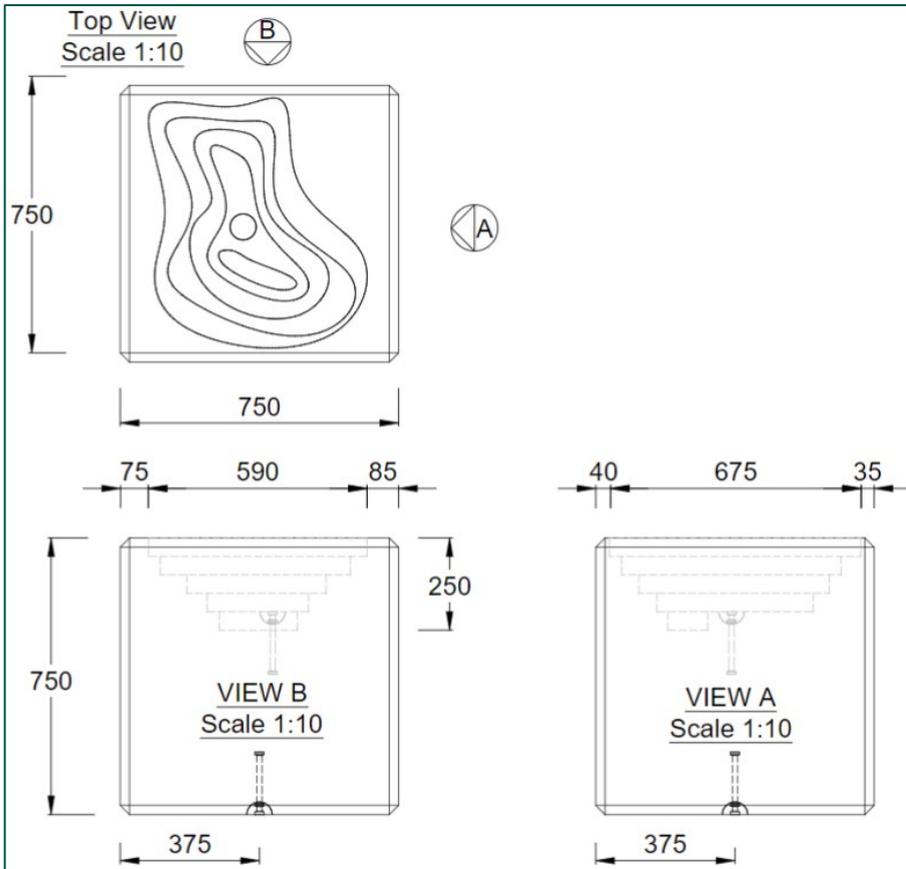
Example of Living Seawalls Panel





JP Concrete

Example of Breakwater Eco-Armour



1. Design & Manufacture

- a) Design Life: 50+ years.
- b) Tolerances: $\pm 5.0\text{mm}$ in all dimensions according to BS EN 13670:2009.
- c) Manufacturing to BS EN 13369:2013.

2. Concrete

- a) Lifting cube strength = 15 N/mm^2 .
- b) Characteristic 28 day cube strength = Minimum of 40 N/mm^2 .
- 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 $\pm 10\%$

** Weight to be checked by the main contractor.

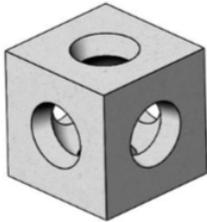
Note: The weights and volumes presented above are an estimate, the final product will depend on the Biomimicry design used.

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

ARC Marine

Example of Reef Cube

REEF CUBE® DATASHEET



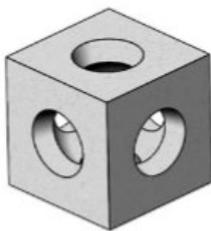
- Made from 98% recycled materials.
- 100% plastic free.
- Carbon neutral - contains no Portland cement.
- Certified as non-toxic to the marine environment.
- Strength > 35N/mm² (> 35MPa).
- Encourages marine growth / biodiversity.
- Multiple marine applications

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

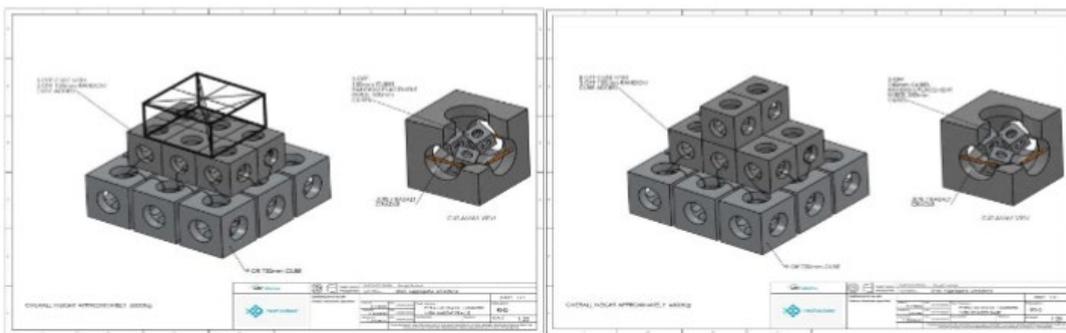
*Weight in air based on a typical average density of 2,150kg/m³.

*Densities typically range from 2050-2250kg/m³. For bulk orders we manufacture locally hence product density & weight is subject to local variation of the sustainably sourced aggregate.

HYBRID PYRAMID® DATASHEET



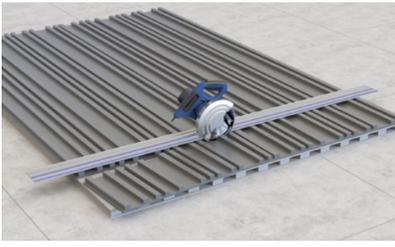
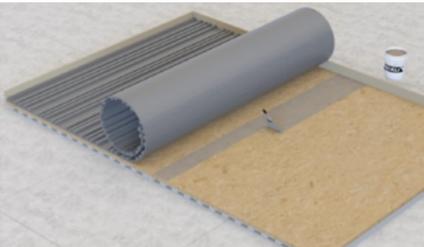
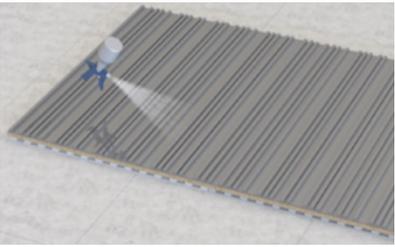
- Deliberate marine habitat enhancement
- Encourages marine growth / biodiversity.
- Provides elevated chambers and substrate
- Designed for cod, cephalopods and sharks
- Made from 98% recycled materials.
- 100% plastic free.
- Carbon neutral - contains no Portland cement.
- Certified as non-toxic to the marine environment.
- Strength > 35N/mm² (> 35MPa).
- Stable under typical North Sea conditions.



Reckli



Application guide example

<p>1 Preparing the mould + 2 Preparing the formliner</p>	<p>3 Inserting, joining and positioning formliners in the mould + 4 Affixing the formliners</p>	<p>5 Apply release wax</p>
		
<p>6 Casting</p>	<p>7 Removal</p>	<p>8 Cleaning the Formliner</p>
