Cyfoeth Naturiol Cymru
Natural Resources Wales

Guidance Note

Coastal Enhancements Guidance

Evidence Base Note

Reference number: 2021/001

Document Owner: Ceri Beynon-Davies

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 flood defence schemes.

Who is this document for?

NRW personnel planning, delivering, and maintaining NRW coastal assets.

Contact for queries and feedback

Ceri Beynon-Davies: ceri.beynon-davies@cyfoethnaturiolcymru.gov.uk

Version History

Document Version	Date Published	Summary of Changes
1.0	03-09-2021	Draft Issue
2.0	02-12-2021	Final Draft Issue - includes output from workshops and addressed comments from Ally Evans
3.0	14-01-2022	Final Issue – addresses comments from NRW

Review Date: [12-2022]

To report issues or problems with this guidance contact Guidance Development

Contents

Contents

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 to deliver requirements mandated on NRW activities; primarily biodiversity enhancement. Drivers requiring the implementation of biodiversity enhancements include: 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 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, such as the type managed by NRW (Section 5.1), 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 locations. For this reason, this document focuses on intertidal eco-enhancements mainly. 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.

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 to assist Flood Defence (Project and Programme Delivery), Strategic Planning & Investment Team / Asset Performance Team and Asset Management Teams (Integrated Engineering) within NRW to embed and apply ecological enhancements into their current and future flood risk projects and operations. 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.

Although this document is developed with a focus on NRW assets, processes and internal structure, it is broad enough to be referenced by other public sector bodies and organisations involved in planning, installing, maintaining or decommissioning coastal artificial structures such as local authorities that would want to explore the opportunities to utilise enhancement solutions in their coastal assets.

2. Context

2.1. 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 is 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.

2.2. 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[1] with almost 400 properties also at risk from coastal erosion[2]. Figure 1 illustrates climate change predictions for Wales by 2050 and 2080.

[1] Flood Risk Assessment Wales, NRW (2019)

[2] National Coastal Erosion Risk Map (2012), most likely scenario under SMP policies over next 100 years.

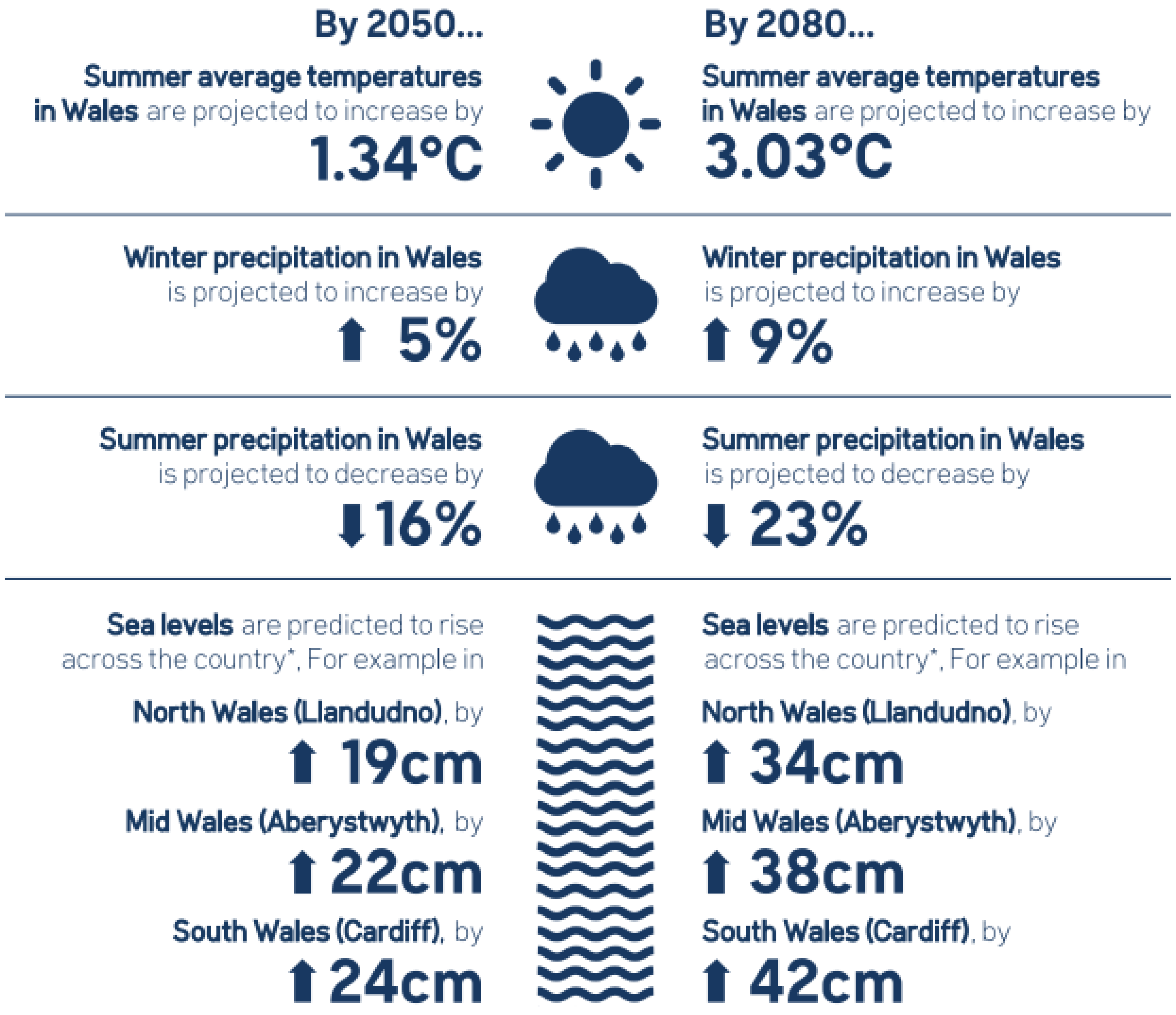


Figure 1 Climate change prediction by 2050 and 2080 taken from UK Climate Projections (UKCP18)[1]. Figure extracted from Historic Environment and Climate Changes in Wales. Sector Adaptation Plan, 2020.

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

[1] UK Climate Projections (UKCP18), Met Office https://www.metoffice.gov.uk/

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.

2.3. 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[1] that grant protection via specified areas for vulnerable habitats and species. The Conservation of Habitats and Species Regulations 2017[2] 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)[3] throughout their distribution. 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[4]:

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.

Section 7 Priority Marine Species[8]: 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.

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[9] have shown that the similarity of grades of rock armour provide the same habitat complexity and ultimately homeogenity across much of Wales'

[1] Wales' Marine Protected Areas Figure: https://cdn.cyfoethnaturiol.cymru/media/691555/area-statement-desig-marine-a4.pdf
[2] As amended by the Conservation of Habitats and Species (Amendment) (EU Exit) Regulations 2019.
[3] 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.
[4] https://www.biodiversitywales.org.uk/File/57/en-GB - only intertidal habitats presented; coastal ecostructures predominantly deployed in the Intertidal zone.
[8] https://www.biodiversitywales.org.uk/File/56/en-GB
[9] Lawrence PJ et al. 2021. Artificial shorelines lack natural structural complexity across scales. Proc. R. Soc. B 288: 20210329. https://doi.org/10.1098/rspb.2021.0329

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 NRW 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 such as: 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 bioprotection for rock surfaces, increasing resilience against erosion. Others are valuable for recreation, tourism and subsistence, e.g. rockpooling, 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 delivering 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[10]. 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[11] 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)[12]. 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

[10] https://pure.aber.ac.uk/portal/en/theses/artificial-coastal-defence-structures-as-surrogate-habitats-for-natural-rocky-shores(a02e7f0b-5a07-4977-9cd9-47ca12856c87).html

[11] NRW to provide link to EcoStructure Tool.

[12] https://gov.wales/sites/default/files/publications/2018-02/invasive-aquatic-species-priority-marine-species.pdf

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.

2.4. 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.[13]

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.

[13] https://naturalresources.wales/about-us/what-we-do/how-we-work/our-well-being-statement/?lang=en

- **Conservation of Habitats and Species Regulations 2017** – requires Habitats Regulations Assessment (HRA)[14] of any proposals that have the potential to affect the National Site Network[15], that are not necessary for the management of that site.
- **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.
- **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.

2.5. Ageing Assets

As part of responding to the Climate Emergency, the NRW Business Plan sets a performance target to maintain flood risk assets in high-risk systems at their target condition. In addition, as NRW look to adapt their assets to cater for the impacts of climate change, a particular challenge is the approach taken to ageing assets. NRW assets range in age, have differing design codes, environmental exposure, usage and maintenance regimes – all of which combine to determine how an asset may respond to a changing climate.

On the other hand, 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

---

[14] Link to NRW Operational Guidance Note (OGN 200), 'Habitats Regulations Assessment of Projects': https://cyfoethnaturiolcymru.sharepoint.com/teams/communications/Intranet/Intranet%20Operational%20Instructions/!OGN%20200%20HABITATS%20REGULATIONS%20ASSESSMENT%20OF%20PROJECTS%20-%20ENGLISH.pdf

[15] Previously referred to as ‘European Sites’ / ‘Natura 2000 Network’, comprising Special Areas of Conservation (SACs), Special Protection Areas (SPAs) and proposed and candidate sites thereof. Does not apply to Sites of Special Scientific Interest (SSSI). It is Government policy that this also includes Ramsar Sites (Wetlands of International Importance).

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 of NRW's 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 must be considered on all project types to ensure the maximum benefits and value are realised.

3. Consenting and Delivery Requirements

Consenting and Licencing – 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 measureable objectives and clarify whether any additional field survey or further assessment is likely to be required.

Marine Licensing - deposits or removals 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[16], whilst typical activities will require a standard Band 2 application. Each application process requires specific supporting information[17], requires payment of a fee[18]

[16] https://naturalresources.wales/permits-and-permissions/marine-licensing/marine-licensing-band-1-low-risk-activities/?lang=en
[17] https://naturalresources.wales/permits-and-permissions/marine-licensing/licence-application-forms/?lang=en
[18] https://naturalresources.wales/permits-and-permissions/marine-licensing/marine-licensing-fees-and-charges/?lang=en

and have determination periods of 3-6 weeks and 16 weeks respectively[19]. The likely consenting route for selected ecoengineering techniques is outlined in Section 5. 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. 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[20].

Consenting and Licencing – Site-Specific

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

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

[19] https://naturalresources.wales/permits-and-permissions/permit-applications-consultations-and-decisions/permitting-service-levels-in-natural-resources-wales/?lang=en

[20] Link to Operational Guidance Note (OGN72), 'Complying with the Water Framework Directive Regulations 2017: how to assess and appraise projects and activities': https://cyfoethnaturiolcymru.sharepoint.com/teams/communications/Intranet/Intranet%20Operational%20Instructions/OGN%20072%20Complying%20with%20the%20Water%20Framework%20Directive%20Regulations%202017%20-%20how%20to%20assess%20and%20appraise%20projects%20and%20activities.pdf

lacking an impact pathway) an HRA may not be required, pending consultation with the relevant NRW Conservation Officer. Refer to NRW OGN200 for details[21].

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. Pending assessment, Scheduled Monument Consent or Listed Buildings Consent may be required.

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

[21] Link to NRW Operational Guidance Note (OGN 200), 'Habitats Regulations Assessment of Projects': https://cyfoethnaturiolcymru.sharepoint.com/teams/communications/Intranet/Intranet%20Operational%20Instructions/!OGN%20200%20HABITATS%20REGULATIONS%20ASSESSMENT%20OF%20PROJECTS%20-%20ENGLISH.pdf

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 5.

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.

Coastal and estuarine areas where artificial structures proliferate, can be popular destinations for tourism and recreation. Incorporating ecological enhancements to the artificial structures presents a great opportunity to enhance cultural services.

Fairchild, T at al. (2018) describe the first direct experimental link between the functional emotion of interest and biodiversity that is likely to facilitate the flow of recreational and educational benefits from ecosystems. The study suggests that managing and enhancing artificial coastal habitats could increase public interest and consequently enhance educational, recreational and tourism value which strengths the case for managing coastal and estuarine structures to improve biodiversity. At the same time, increasing the public interest could be a means of getting support 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 (Salauddin M. et al. ,2021). However, Salauddin M. et al. ,2021 presents laboratory-based physical modelling investigations on the characteristics of wave overtopping on artificially roughened seawalls, concluding that "*reductions in dimensionless mean overtopping rate (by up to 100% in comparison to the plain seawall reference condition) were limited to impulsive (violent) wave conditions, with no significant differences (for all tested roughness configurations) in mean overtopping rates being observed for non-impulsive wave conditions compared to the plain vertical seawall (reference condition)*". The findings are very relevant given that the wave impact hazards associated to impulsive wave conditions are generally higher than for non-impulsive wave conditions. The results suggest that the addition of 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 to demonstrate best-practice 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 and in the general course of NRW duties. Delivery of ecoengineering as coastal enhancement acts to support NRW goals to deliver SMNR, promote resilience of ecosystems and support well-being goals in line with the Environment (Wales) Act and Well-Being of Future Generations (Wales) Act.

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

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 performance, influence on the structural integrity, to unquantifiable ecological benefits.

A benthic habitat assessment[22] 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. 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[23] so that they can be incorporated into the evidence base for future decision-making along side with NRW own reporting and knowledge sharing channels.

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

[22] Benthic habitat assessment guidance: Natural Resources Wales / Benthic habitat assessments for marine developments

[23] https://conservationevidencejournal.com/

support applications, and any site-specific mitigation measures that may be required to support deployment (seasonal restrictions, e.g. breeding / overwintering birds).

4. Planning, Delivery and Maintaining NRW Coastal Assets

4.1. NRW Coastal Assets

This guidance note focuses on coastal and estuarine assets managed by NRW; these are outlined below. It should be noted that the pictures below are examples of the asset type and are not necessarily assets managed by NRW.

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

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)

4.2. NRW Organisation and Processes

This section outlines the processes that NRW projects follow from inception to implementation, highlighting how ecological enhancements should be considered as part of the different phases of the project development.

The processes vary depending on the type of project, for that reason we differentiate here between revenue projects - more frequent and routine works that generally require lower funding, and capital projects - one-off projects that generally require greater funding.

Revenue Projects

Revenue projects include routine activities such as small-scale repairs and vegetation management, and smaller scale capital projects which are more significant one-off/ad hoc refurbishments and repairs.

For maintenance and minor upgrades / repairs to structures, the Asset Performance Teams (APT) set the standard for the asset, the 'what', and then the Integrated Engineering Teams (IET) undertake the necessary environmental assessments / consents, develop scope (the 'how') and deliver the required work to meet the standard set. Because of the reduced scale and complexity of works that fall within this process, it is not defined in the same detailed way that larger scale capital projects are. The IETs manage this type of project through the team budgets they hold.

For small capital works, the IETs have to bid via the Flood Risk Management (FRM) Strategic Planning & Investment Team for project funds (via a project brief) and outline what they want to deliver with appropriate justification. The usual range for bidding for capital funds from the Strategic Planning and Investment team is £5k-£50k. Works above the £50k (up to a limit of £250k) can be delivered by the Integrated Engineering teams if the work is not considered to be complex. Any work between the £50k-£250k threshold requires a formal business case submission and sign off by the business board.

Over the next couple of years, NRW intends to undertake a piece of work which scrutinises the maintenance schedule for revenue projects, ARBRAM project (A Risk-Based Revenue Allocation Model). The tool / model would consider the costs and benefits of undertaking the work to enable maintenance "activities" to be ranked. Funding would then be allocated in order of priorities and risk. The project outputs can then assist in justifying more funding where appropriate as well as areas where maintenance activities and expenditure cannot be justified, and withdrawal of maintenance process may need to be applied. ARBRAM will therefore clarify the locations and assets which will continue to be maintained and may therefore inform where investment in eco-enhancements might be more viable.

A flow chart presenting the organogram of the teams delivering revenue projects, the process they follow and how ecological enhancement fit is presented in Figure 2.

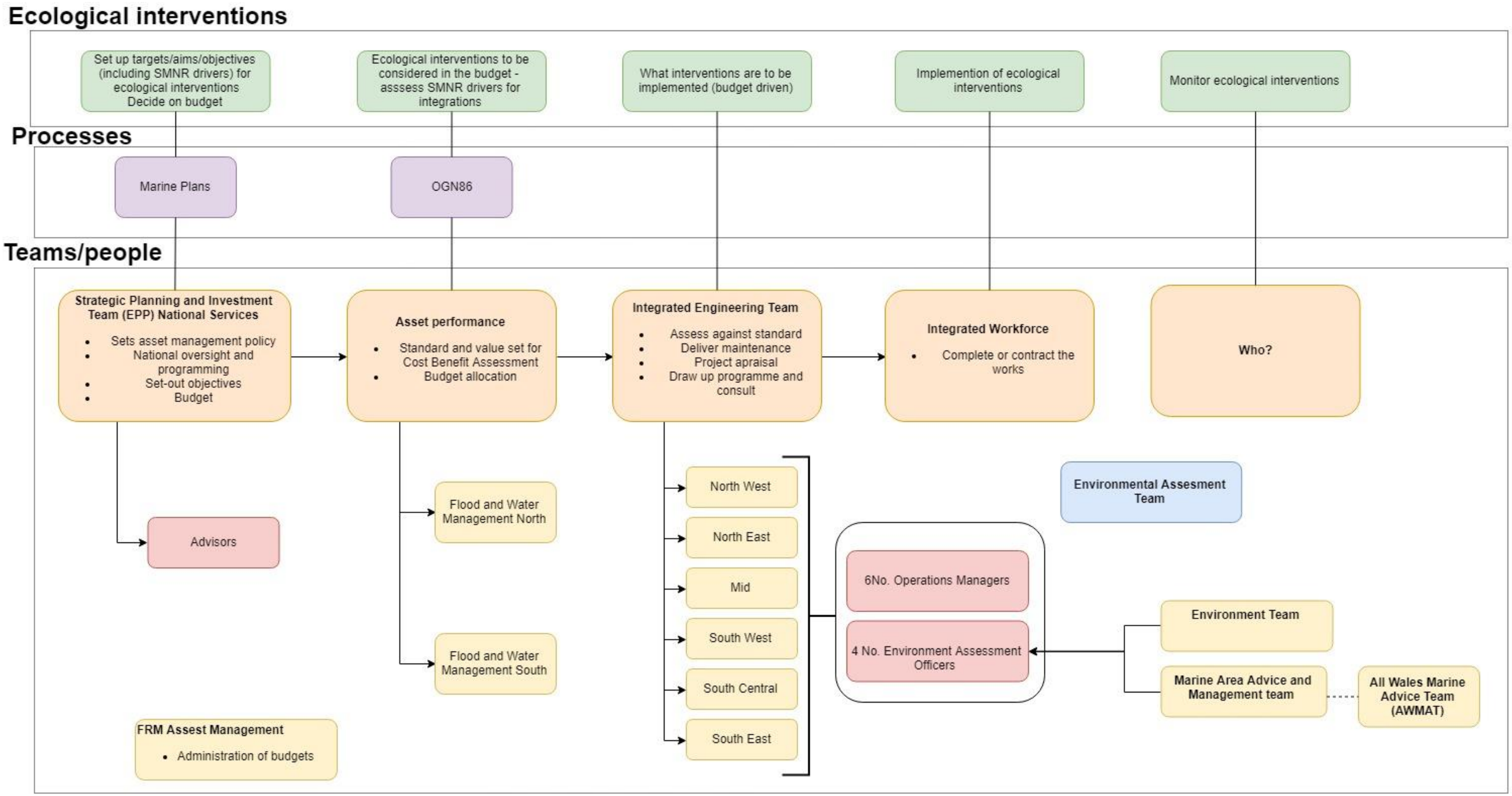
Capital Projects

Capital projects generally involve the construction of a new asset or a significant refurbishment/enhancement of an existing asset.

The processes to take capital projects from inception to delivery are well defined and can be found in the Business Case Guidance for Flood and Coastal Erosion from Welsh Government[24] and OGN 133: Flood Risk Management Initial Assessment (NRW internal guidance). A summary of those processes and how ecological enhancements fit is presented in Figure 3. It should be noted that depending on the risk profile of the project, only some gateways and their corresponding Governance documents showed in Figure 3 may be applicable.

Figure 4 presents an organogram of the teams / people involved in the delivery of capital projects.

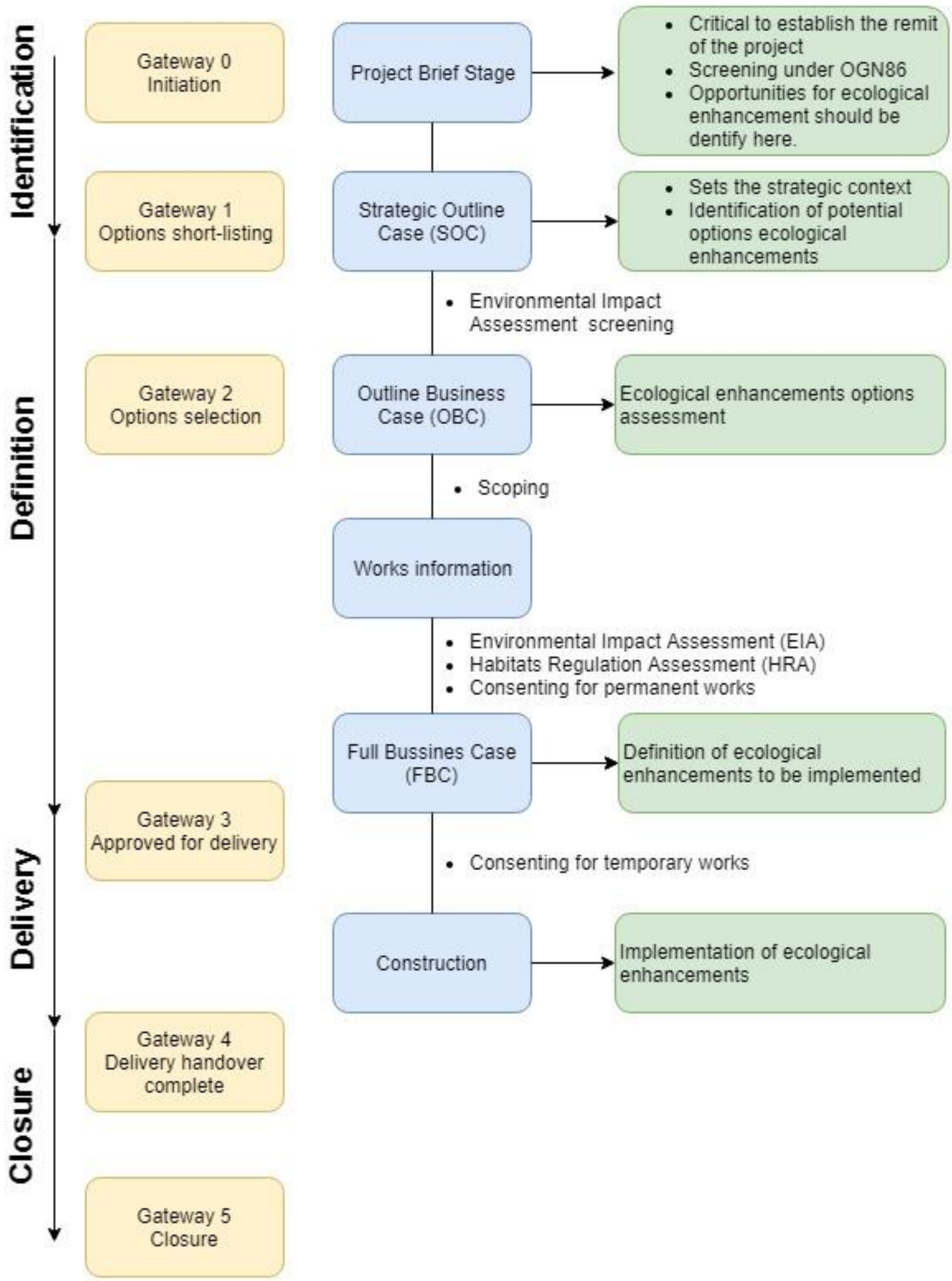
[24] Flood and Coastal Erosion Risk Management - Business Case Guidance



Notes:

- SMNR: Sustainable management of natural resources
- Environmental Assessment Team are not very involved during maintenance. They would screen if any of the activities are considered capital

Figure 2 Revenue projects from inception to implementation flow chart



Note:

- Flood Risk Management Board has a direction and assurance role.
- Environment Teams Advise and Assent - review the EIA and HRA and consider de application in relation to Section 28 of the Wildlife and Countryside Act (WCA) 1981.
- Environment Teams consulted by Marine Licecing for any activity below Mean High Water.

Figure 3 Capital projects from inception to implementation flow chart

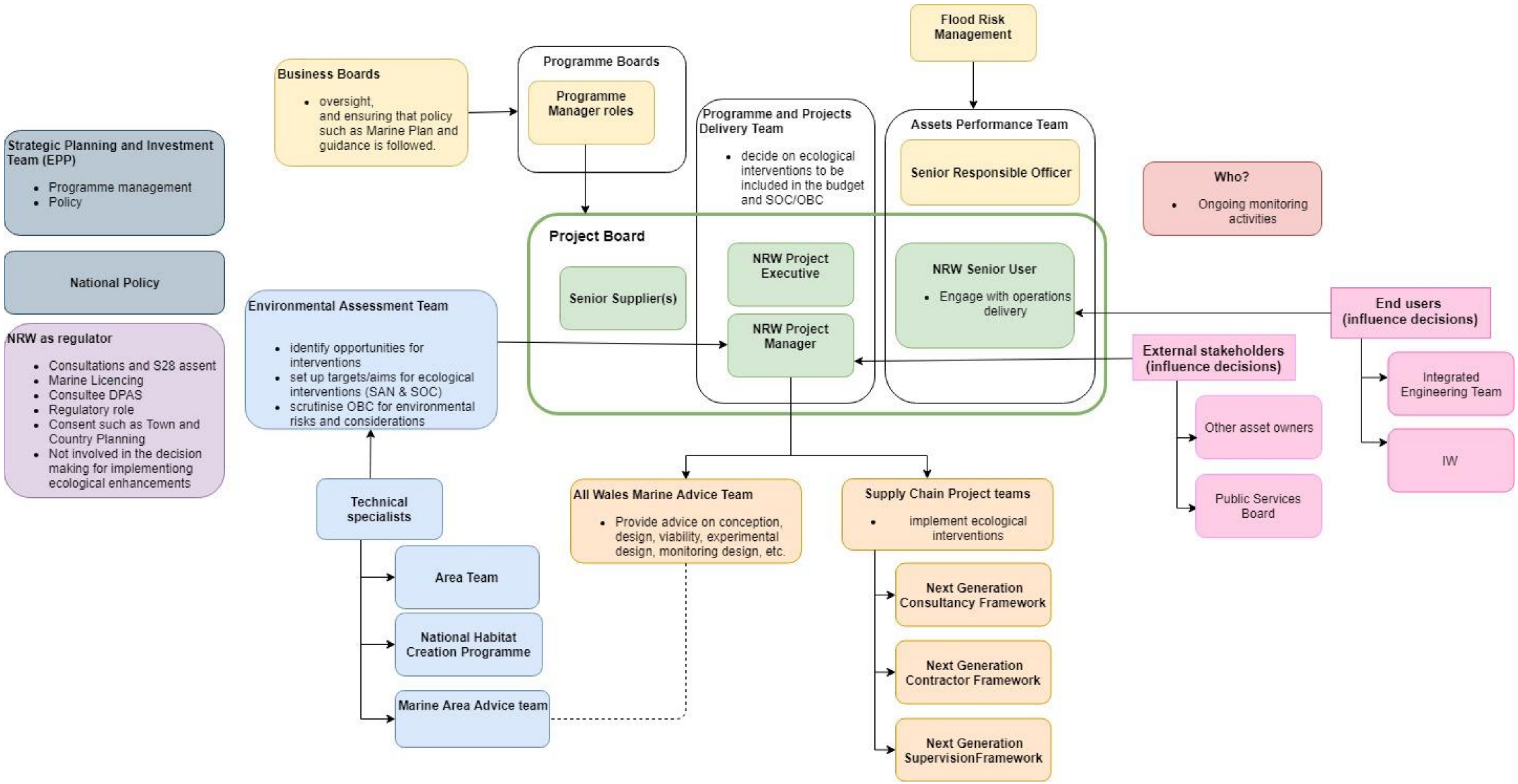


Figure 4 Structure of the teams delivering capital projects

4.3. Barriers to Implementation of Ecological Enhancements within NRW

A number of internal workshops have been held with the aim to identify the barriers, within NRW, to the implementation of ecological enhancements. The identified barriers 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 team and budget to undertake ongoing monitoring which is key to measure success, record learning and to build on the evidence base of ecological enhancements. • Funds not allocated to facilitate community engagement to understand how the public perceives ecological enhancements. • Funding of ecological enhancements is particularly challenging for revenue projects (see Section 4.2 for definition) as the budgets are adjusted to undertake maintenance and repair works without headroom for enhancement and improvement. • For much of the work delivered via operations teams (revenue projects) there is concern that incorporating ecological enhancements, may be disproportionate to the maintenance activity itself, e.g. repointing a wall or cutting back vegetation. • NRW is working to review Flood Risk Management revenue maintenance funding (see ARBRAM project in Section 4.2). This review aims to focus on outcomes and to make risk-based decisions. However, it currently does not consider enhancements. • Implementing ecological enhancements requires change to the ‘status quo’. Lack of resources (people and budget) to focus on overcoming the resistance to change within NRW. • Lack of a resource within the Integrated Engineering Team with a dedicated focus on assessing and delivering the most appropriate ecological enhancement in each location (see Figure 2). • Teams are very busy and have limited time to learn more and keep up to date with the latest on ecological enhancements and to link in with others on the subject.
Upskilling and Knowledge Sharing
• Poor awareness on the drivers and requirements for implementing ecological enhancements. • 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 - 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. - Manufacturers - How to select the right intervention - Impact to standard of protection - Cost

• Not promoting and advertising the wider benefits of implementing ecological enhancements. • Lack of information sharing
Organisation and Processes
• Lack of understanding of the processes and teams involved in taking ecological enhancements from inception to deployment. For example, the environmental teams raised that they were not clear on how enhancement ideas can be fed into the process. • Lack of reference to key policy and legislative drivers to incorporate ecological enhancements to existing structures, 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 (revenue projects). • Opportunities for ecological enhancements are not being consider from the project inception leaving limited influence to decisions at later stages of the project. • Community engagement is not being considered from the outset of the project missing their buy in. • Complex organisation with many teams and specialists. There isn't a clear understanding of what the different teams do and therefore, who to consult about ecological enhancements. • Lack of linkages with other teams to assess wider benefits of ecological enhancements. • Not clear who/which team will maintain and provide ongoing monitoring of ecological enhancements.

4.4. Actions for Effective Implementation of Ecological Enhancements within NRW

Actions to overcome the barriers identified in Section 4.3 were discussed during the workshops and are presented below:

Resources - People and Budget
• Budget to support the implementation, from inception to deployment, of ecological enhancements needs to be considered by Asset Performance (for small capital projects delivered by the operations teams) and Strategic Planning and Investment team (EPP) when setting programmes and plans. • Resources (people) to support with expert input into the implementation decision, from inception to deployment, of ecological enhancements need to be made available for projects so the cost impact on the IETs budget is reduced. • Appoint a team/teams whose remit is on-going monitoring and maintenance of ecological enhancements. Suitable budget and people would need to be allocated to that/those teams. • Target ecological enhancements through their own programme of installations on existing assets (where retrofitting is appropriate). A short-term targeted programme could enable more embedded delivery in the future when confidence and experience has grown and there is less concern about additional staff time and funding for

delivery and therefore ecological enhancements can be incorporated via existing programmes. • Bid to Welsh Government Water Capital fund for the delivery, deployment and monitoring of ecological enhancements. Other funding opportunities can also be considered under Flood & Coastal Erosion Risk Management.
Upskilling and Knowledge Sharing
• Understand what is included in this guidance document. A training toolbox is available to disseminate the content of this note (see Appendix B). • To include the training toolbox (see Appendix B) in the technical development framework for relevant teams. • To 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. • To publicise and celebrate those projects where ecological enhancements are being or have been implemented. Identify metrics to quantify enhancement benefits. • To 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 posted in a dedicated Yammer group. • Name a champion in each team to sign into newsletters from providers and research to keep up to date on the latest on ecological enhancements and cascade to others.
Organisation and Processes
• Understand what is included in this guidance document which outlines the roles of the different teams involved in delivering ecological enhancements. A training toolbox is available to disseminate the content of this note (see Appendix B). • Supplement existing guidance such as FCERM and Business Case Guidance 2019 to include up to date policy drivers for example Marine Area Statement, Welsh National Marine Plan 2019 and National Strategy for FCERM 2020. • Supplement the Business Case Guidance 2019 to prompt and identify opportunities for ecological enhancements. • Establish a clearer internal consultation process which clearly defines who to consult and seek for advice and that encourages early engagement from the project team with specialists across NRW to identify opportunities for ecological enhancements. • The Asset Performance Team to set clear requirements to deliver ecological enhancements so the Integrated Engineering Teams can deliver those. For the Asset Performance Team to set the requirement for eco-enhancements, a steer on how eco-enhancements should be considered within the work delivered by Asset Performance Team and Integrated Engineering Teams is required. • Ecological enhancements should be included as an item in the agenda when discussing the wider project with stakeholders. • Joining 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[25].

[25] Habitat Restoration Report by NRW

5. Ecological Enhancements

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.

Ecology • Native species biodiversity • Habitat complexity • Invasive species management • Supporting protected site objectives • Promoting specific target species • Mimicking natural rocky habitats/biodiversity	**Environmental** • Water quality • Carbon sequestration • Biofiltration	**Economic** • Job creation • Business opportunity • Shore protection insurability
Engineering • Energy attenuation • Shoreline stabilisation • Structural integrity	**Social** • Aesthetics • Tourism and recreation • Education	**Governance and policy** • 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[26]). 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 has an influence on what species ae likely to colonise but also there are interventions that may not resist wave / current actions.
- Sediment processes – interventions may be filled with sediments or may not resist abrasion process.
- 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.

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.

[26] Benthic habitat assessment guidance: [Natural Resources Wales / Benthic habitat assessments for marine developments]

Step 7

Refine the broad goals set as part of Step 1 by setting **measurable and realistic objectives** based on all the above.

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)[27], 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.

[27] Link to Conservation Evidence Synopsis https://www.conservationevidence.com/data/index?synopsis_id%5B%5D=44

Table 1: Interventions - For a more exhaustive list of interventions and details refer to Conservation Evidence Synopsys by A.J Evans et al.

Interventions	
• Use environmentally sensitive materials	• Textured surfaces (Depressions and/or elevations ≤ 1mm)
• Create rock pools (Retain water, depth >50mm)	• Pit habitats (Depressions with a length to width ratio ≤ 3:1 and depth >50mm depth 1-50mm)
• Create groove habitats (Depressions with a length to width ratio >3:1 and depth 1-50mm)	• Create hole habitats (Do not retain water, depressions with a length to width ratio ≤ 3:1 and depth >50mm)
• Create swim through habitats	• Create crevice habitats (Depressions with a length to width ratio >3:1 and depth >50mm)
• Create protrusions (Protrusion with a length to width ratio ≤ 3:1)	• Create ledges or ridges (Protrusion with a length to width ratio > 3:1)
• Create flexible habitats (Materials such as rope, ribbon or twine)	

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 (ns) effects relative to controls. 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.*

Response	**Number of Species**				**Abundance of Species**				**Number of Species or Abundance of Habitat-forming Taxa**			
Microhabitat	**Sessile**	**Mobile**	**Benthic**	**Fish**	**Sessile**	**Mobile**	**Benthic**	**Fish**	**Barnacles**	**Bivalves**	***Tubeworms****	**Canopy algae**
Intertidal interventions												
Texture	(ns)				+				+	-	+	(ns)
Crevice	+	ns	ns		+	(+)	ns		+	+	ns	ns
Pit			+			(+)	ns		+	(+)	ns	ns
Rock pools	+	ns	+	(+)					ns	ns	ns	+
Subtidal interventions												
Texture	(ns)				+				-	+	+	
Crevice	ns				ns				ns	ns	ns	ns
Pit									(ns)		ns	
Holes				ns		+		ns			ns	

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

Step 9

- 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 the different NRW managed 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)	• Cut-in (to create a cavity from the surface)
• Cast-in (to create a protrusion or depression when the material is still malleable, e.g. wet concrete).	• Bolt-on (to attach to the asset using bolts or anchors)
• Drop-in prefabricated units **(**to put into place prefabricated units to form part of the asset)	

Table 4: Techniques applicability to the different NRW managed assets. Assets have been sorted descending order by the number of assets that NRW currently manages.

Installation technique / type of asset	Drill-in	Cut-in	Cast-in	Bolt-on	Drop-in prefabricated units
Outfall	✓	✓	✓	✓	
Open channel	✓	✓	✓	✓	
Wall - includes concrete and masonry walls	✓		✓	✓	
Embankment					
Gabions	✓			✓	
Rock armour and riprap	✓			✓	✓
Concrete faced	✓		✓	✓	✓
Ramps and slipways	✓	✓	✓	✓	
Weir	✓		✓	✓	
Steps	✓	✓	✓	✓	
Groynes					
Rock armour and riprap	✓			✓	✓
Concrete	✓	✓	✓	✓	✓
Bridge abutment					
Piers and piles	✓		✓	✓	
Scour protection – riprap	✓			✓	✓
Spillway	✓		✓		

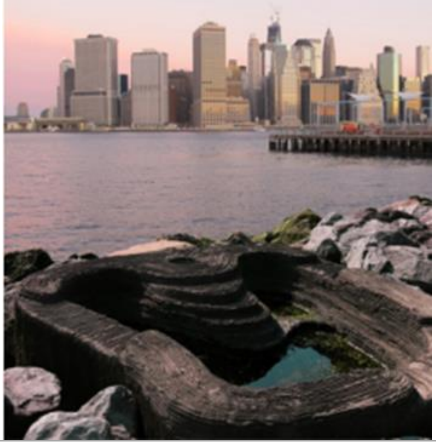
Step 10

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. These products have been selected based on their suitability for NRW managed assets (see Section 4.1). 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 team and considered as part of step 3.

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.

Products from Specialist Suppliers		
Vertipools www.artecology.space		<u>Intervention</u>: • Create rock pools <u>Installation technique</u>: • Bolt-on
BIOBLOCK		<u>Intervention:</u> • Create rock pools • Create pit habitats • Create crevice habitats <u>Installation technique</u>: • Drop-in prefabricated units
EConcrete rock pools https://econcretetech.com/		<u>Intervention:</u> • Create rock pools • Texture surfaces <u>Installation technique</u>: • Drop-in prefabricated units

Products from Specialist Suppliers		
EConcrete® seawall panels https://econcretetech.com/		Intervention: • Create rock pools • Create hole habitats • Create ledges or ridges Installation technique: • Bolt-on
ECOncrete® piles and jackets https://econcretetech.com/		Intervention: • Use environmentally sensitive materials • Textured surfaces Installation technique: • Cast-in
Living Seawall panels [Living Seawalls — REEF DESIGN LAB]()		Intervention: • Use environmentally sensitive materials • Create rock pools • Create hole habitats • Create crevice habitats Installation technique: • 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. '*Examples 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 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.
- 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).

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.

Further to Table 6, other combinations of installation techniques and interventions are possible. Examples of the techniques presented in Table 6 and others, chosen based on the potential suitability for NRW assets, are presented below. 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 Appendix C 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 provide 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 (from 1 to 5 – 1 being low and 5 being 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.

Ecological enhancement[28]	Capital cost	Ecological potential[29]	Asset management challenges	Additional benefits[30]
Rock structures				
Drill-in pits and grooves	1/5	2/5	1/5	1/5
Drill-in rock pools	2/5	3/5	2/5	2/5
Drop-in precast enhancement units (with several habitat interventions)	5/5	5/5	3/5	4/5
Bolt-on precast tiles and panels (with several habitat interventions)	3/5	3/5	3/5	3/5
Vertical concrete faced structures				
Drill-in pits, grooves and crevices	1/5	2/5	1/5	1/5
Bolt-on precast tiles and panels (with several habitat interventions)	5/5	4/5	4/5	4/5
Bolt-on vertical pools	3/5	4/5	5/5	3/5
Cast-in textured concrete	4/5	3/5	3/5	3/5
Bolt-on green wall modules	2/5	3/5	4/5	2/5

[28] The information presented in this table is based on experience, the cases studies and literature review presented in Appendix A and C.
[29] Refers to ecological potential for species richness. The ecological benefits for each selected technique would need to be measured against the project-specific objectives.
[30] In addition to ecological potential, including social benefits, wider environmental benefits and engineering benefits.

The following notes apply to all nine techniques discussed below:

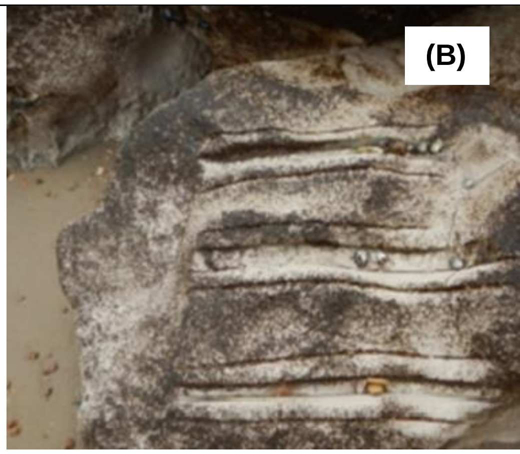
i. These examples are not exhaustive but provide a reference or point of discussion on the benefits and challenges that may be encountered while incorporating ecological enhancements to existing structures. The examples included are taken from several studies. The issues discussed in the following tables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

<table>
<tr><td colspan="2">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.</td></tr>
<tr><td>

[Source: Hall et al, (2018)]</td><td>

[Source: Hall et al, (2018)]</td></tr>
<tr><td>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).</td><td>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.</td></tr>
</table>

• 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.	

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 the 14mm and 22mm pits (Firth et al.,2014).

Timescales

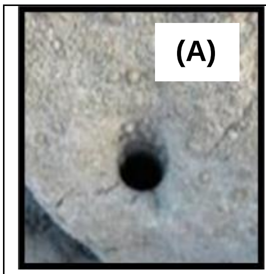
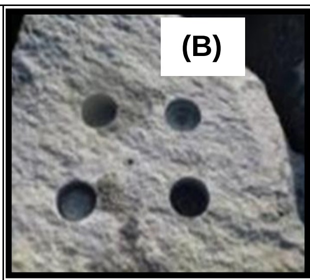
- Likely consenting route: drilling (removal activity) – likely no marine licence when undertaken on an artificial structure; confirm with NRW MLT in advance. Any sacrificial layer would need to be integrated into the design or would require a marine licence to deploy post-development.
- Pits in granite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

<table>
<tr><td>
[Source: Firth et al.,2014]</td><td>
[Source: Evans et al., 2016]</td></tr>
<tr><td>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.</td><td>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.</td></tr>
<tr><td>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.</td><td>Cost
• (A) It took two workers approximately. two hours to in-fill nine cores. No skilled labour was required.
• (B) Approx. £50/pool.</td></tr>
</table>

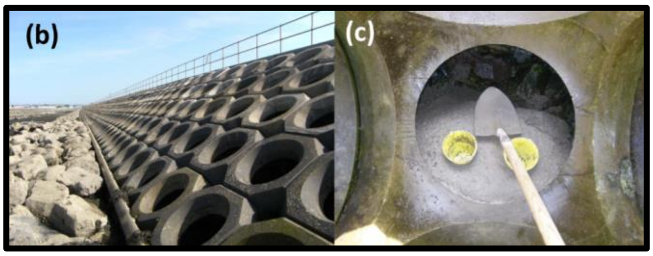
Timescales

- 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).



[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 (Firth et al.,2014).
- 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	**Cost**
• 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.	• 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.

(A)

ECOncrete® piles and jackets

(B)

Outfall pipe on Hannafore beach in West Looe, Cornwall

Maintenance and asset management considerations	**Challenges: limitations and risks**
• No different to business as usual.	• 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. • 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	Timescales
• The cost of the textured tiles for Hannafore project was ~£1000/m^2.	• 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.

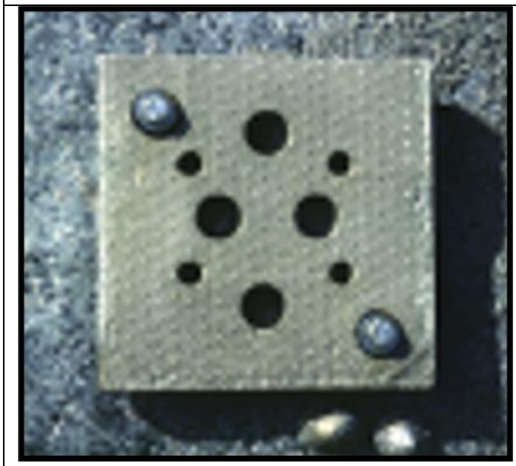
Technique 5 – Bolt-on precast panels and tiles

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 update – image courtesy of Ruth Callaway from Swansea University

Living Seawall panels

ECOncrete® panels in a seawall

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.

Cost

- Living Seawall panels - £175 per unit (note these are currently manufactured in Australia so delivery cost and carbon footprint could be significant).

• Living Seawall panels have a typical design life of 20 years.	• Additional cost of design and production of textured formwork than business as usual. From Naylor et al. (2017), in the Hartlepool example, it cost an extra £8-£30 per m^2 compared to plain cast formwork.

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.

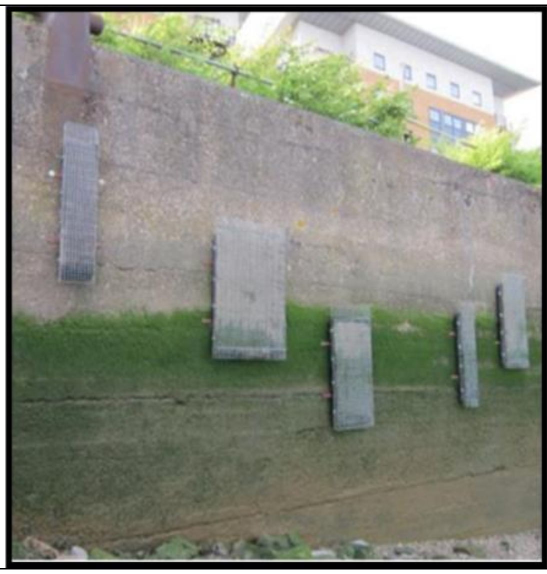
Effectiveness: benefits assessment	Challenges: limitations and risks
• Ecological - These and other similar structures have the capacity to provide habitat where previously there was little or none water-retaining habitats and could support locally significant populations. • There is potential to adapt the pools to mimic specific habitat for individual species or target communities. • Where coastal squeeze becomes significant Vertipools could become	• 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.

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).	• 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. www.artecology.space
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.



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

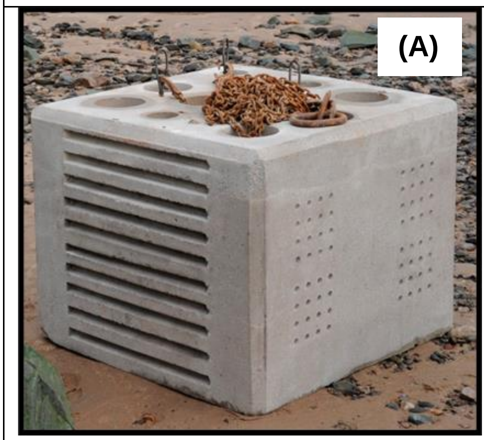
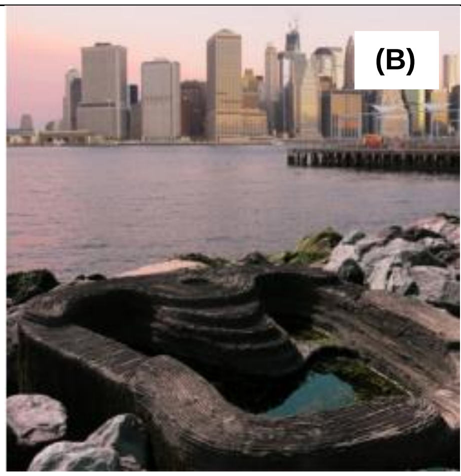
- Modules should be installed at an angle, i.e. not vertical, to encourage a good level of plant coverage and species richness.
- Some people remarked the untidy appearance, potential wall damage and the risk of trapping litter.

Cost

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

• Vegetation establishment on the vertical wall modules was disappointing; trough features more effective.	
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 us rockpools, pits, crevices, etc. within each unit. They can be incorporated into riprap structures, rock revetments, rock groynes and rock breakwaters. BIOBLOCK (A) is a large, precast habitat-enhancement unit comprising multiple habitat-enhancement types (rock pools, pits, crevices) that would be present on the boulders of a structure (Firth et al., 2014). Tide Pool Armour (B) is a modular water-retaining unit that mimics natural rockpools.	
 [Source: Naylor et al., (2017)]	 ECOncrete
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	**Maintenance and asset management considerations** • They can be installed during construction or retrospectively. • BIOBLOCK should last >10 years (Naylor at al., 2017). • Deposition may need to be removed after large storms if not cleared naturally.

reduces fluctuations in temperature and salinity allowing more resilient communities. • Wider environmental benefits – they facilitate climate change resilience through supporting biodiverse ecosystems.	
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/helpourkelp Alternatively, kelp may be transplanted / seeded onto structures in appropriate locations to deliver gains earlier.

<table>
<tr><td colspan="2">• 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.</td></tr>
<tr><td>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.</td><td>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.</td></tr>
<tr><td>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.</td><td>Cost
• Habitat restoration typically large-scale and resource intensive, greater costs than standard interventions.
• Potential to link with NGOs, charities and wider funding opportunities.</td></tr>
<tr><td colspan="2">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.</td></tr>
</table>

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. 8No. 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/m^3 or 4 hours for 48 boulders) than granite (£55/m^3 or 2 hours to retrofit 12 boulders). This equates to ~£17/m^3 and £88/m^3 in additional costs to add the enhancements onto limestone and granite, respectively. Standard rock armour for revetments costs between £42 – 107/m^3. Adding drill holes to the granite rock armour would be approximately 1.2 to 2 times the business-as-usual costs for commercial rock armour. This means it would cost between £130 -£195/m^3 for combined rock purchase and drilling costs. For limestone these costs would be lower, adding between 15-40% to the cost of business-as-usual rock armour, thus costing between £84-£150/m^3.

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 5 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/m^3. This compares to between £63 – 93/m^3 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[31].

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.

Figure 6 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[32]

‘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

---

[31] Source: https://www.plymouth.ac.uk/news/bioblocks-show-how-coastal-designs-could-benefit-marine-life
[32] Source: https://www.northsydney.nsw.gov.au/Environment_Waste/Sustainability/What_is_Council_Doing/Living_Seawalls_Project

Sydney, making it the largest retrofit of a Living Seawall in Australia, and potentially the world.

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

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

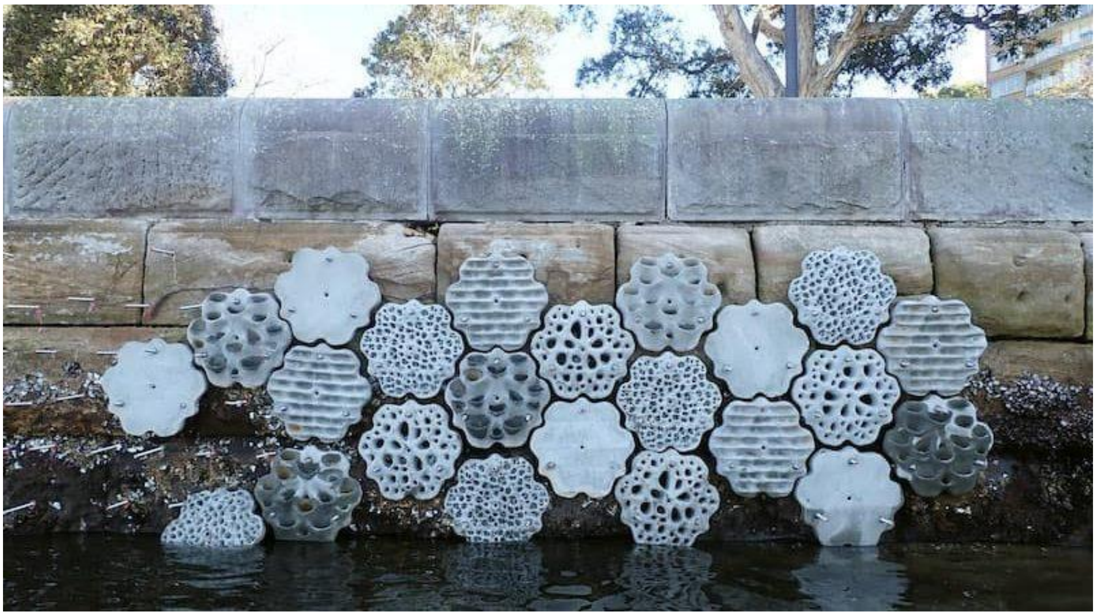


Figure 7 Living Seawalls at Sydney Harbours. [Source:https://www.sustainabilityhackers.com/living-seawalls-to-bring-new-life-to-rushcutters-bay/]

Tiles retrofitted to Mumbles Sea-Hive Project, The Mumbles, Wales.[33]

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.

[33] 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).

Figure 8 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 Bouldner, 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.

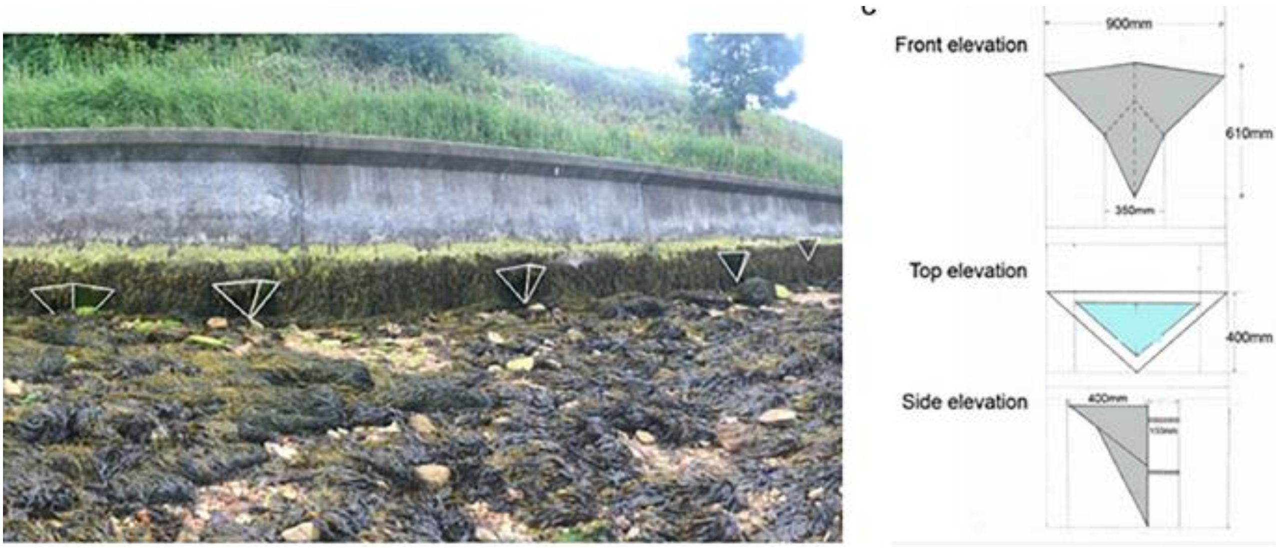


*Figure 9 Location of the Vertipools on the seawall (left) and dimensions of the Vertipools (right) [*Source: From Hall et al. (2019)]

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 10 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/m^2).

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.

(a) (b)

Figure 11 (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 45º 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 45º 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 B – Training Toolbox

[To be completed in due course]

Appendix C – References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

22. Hall, A.E., Herbert, R.J.H., Britton, R.J., Boyd, I. & George, N. (2019). Shelving the Coast With Vertipools: Retrofitting Artificial Rock Pools on Coastal Structures as Mitigation for Coastal Squeeze. Frontiers in Marine Science, 6, 456. 10.3389/fmars.2019.00456

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

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

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

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

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

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

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

30. Metcalfe, D (2015). Multispecies Design. P hD thesis, University of the Arts London and Falmouth University.

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

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

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

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

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

36. O’Shaughnessy K.A., Hawkins S.J., Evans A.J., Hanley M.E., Lunt P., Thompson R.C., Francis R.A., Hoggart S.P.G., Moore P.J., Iglesias G., Simmonds D., Ducker J. & Firth L.B. (2020) Design catalogue for eco-engineering of coastal artificial

structures: a multifunctional approach for stakeholders and end-users. Urban Ecosystems, 23, 431–443.

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

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

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

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

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

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

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

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

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

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

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

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

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