# Appendix 8.3

# Artificial Structures in Coastal Habitats: Optimising the value for biodiversity by creating an artificial reef

# Artificial structures in coastal habitats

*Optimising the value for biodiversity by creating an artificial reef*

**Report for Tidal Lagoon (Swansea Bay) plc**

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| SEACAMS contract | B56 |
| | This review fulfils part of the contract "Determining the key issues related to artificial substrate as a coastal habitat for enhancing marine renewable developments" |


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## Summary


I. Artificial coastal structures can supplement the natural environment by providing a substrate that will support marine organisms, thereby functioning as an artificial reef.

II. The structural diversity of the artificial reef will determine the diversity of marine organisms utilising created habitat.

III. Negative effects of artificial reefs can potentially be the provision ‘stepping stones’ for invasive species if little other hard substrate is available. In Swansea Bay this may be less problematic since there is already a considerable amount of natural and artificial hard substrate available. However, monitoring should include checks for invasive species.

IV. Positive effects of artificial reefs include the enhancement of biodiversity of invertebrates and fish. Hard substrates such as rock armour provide attachment surfaces for species that themselves create reefs, for example oysters, mussels or tube-building worms (e.g. the Sabellaria honeycomb worm). These accelerate the reef-building process.

V. Diversity promoting design solutions can be included in the planning and construction phase of the tidal lagoon wall to attract large numbers of species and to reduce the impact on the surrounding environment.

VI. The specific advice for TLSB in this report follows recently produced guidelines which are based on rigorous scientific research.


## Recommendations

In order to maximise benefits of the lagoon wall for the environment, the following general principals should be considered:

i. *Avoid smooth rock material.* Few organisms will colonise homogeneous surfaces and species colonisation rates will increase with surface roughness. Where possible, use a mixture of hard and soft rock. Soft rock (e.g. limestone) will erode quicker than hard rock (e.g. granit) which will create surface roughness and habitat for attachment of marine organisms.

ii. *Create rock pools, pits and crevices.* Rock pools, pits and crevices provide refuges for intertidal organisms and can sometimes support greater diversity than emergent substrata. They can be created by drill-coring into boulders.

iii. *Incorporate precast reef units in or around the lagoon wall*. Artificial units that are designed to maximise the number of attracted species promote biodiversity and can provide protection from erosion.
iv. Facilitate 'soft' engineering. They include the creation of saltmarshes, seagrass meadows, oyster and mussel beds and tube-worm reefs (*Sabellaria*). These features offer protection from hydrodynamic impacts, retain sediment and reduce erosion, but they also diversify the habitat.

| **Summary of recommendations for the TLSB** | |
|---|---|
| 1. | The surface of the rock armour should be uneven and as porous as possible. |
| 2. | A mixture of different materials should be used as rock armour. Some of the material could be softer than others, thus allowing different degrees of erosion. |
| 3. | The surface of the rock armour could be modified artificially. Ridges, crevices and depressions could be deliberately chiselled into the lagoon wall. |
| 4. | Artificial rockpools could be added to the rock armour of the lagoon in the inter and subtidal area. |
| 5. | Precast reef blocks such as 'BIOBLOCKs' or 'Reefballs' could be integrated into the lagoon wall to maximise diversity of colonising species. |
| 6. | Gabion-type cages and matrasses filled with local bivalve shells could be integrated into the lagoon wall to attract benthic invertebrate fauna. Shells could include waste from shell-fish processors and restaurants |
| 7. | The slope of the foot of the lagoon wall should be drawn out and shallow. |
| 8. | Habitat properties of the species-rich area around Mumbles Pier should be analysed and as far as feasible re-created at a suitable location outside the tidal lagoon. |
| 9. | A program to create native oyster reefs (*Ostrea edule*) inside the lagoon should be facilitated. |
| 10. | A program that promotes the restoration of honeycomb worm reefs (*Sabellaria alveolata*) should be facilitated. |
| 11. | Experiments to create seagrass habitat inside the lagoon could be supported. |
| 12. | Further opportunities to create multi-species, integrated multi-trophic systems inside the lagoon area should be explored. |

# 1.0 Introduction

1.0.0.1 Tidal Lagoon Swansea Bay plc (TLSB) proposes to construct a tidal energy lagoon. The structure will be made up of a 9.5 km breakwater wall extending out from the Port of Swansea, and it will enclose an 11.5 $km^2$ tidal area. The nature of the project requires rocky building materials which will be placed on top of inter and subtidal soft substratum in Swansea Bay. The lagoon wall will add to the existing rocky shore in Swansea Bay. Change in the fauna of the lagoon area is unavoidable since soft and rocky shores are colonised by different species communities, with some overlap. In this report we accept that the presence of the lagoon will alter the nature of the invertebrate and fish community, but it is deemed desirable to optimise the lagoon design so that it functions as an artificial reef. The use of different materials, textures and structures could affect the number of species attracted to the lagoon wall and the biodiversity of marine life it supports.

1.0.0.2 The need for artificial coastal structures is going to continue in the form of sea-defences in response to climate change and rising sea-levels, for coastal developments such as harbours, jetties and pontoons and for marine energy structures, such as oil and gas platforms. Marine renewable energy installations are also becoming much more frequent with the need to shift focus of energy production away from fossil fuels and towards renewable energy. Specifically round 3 and 4 of the Crown Estate offshore wind licence auctions will result in a potentially vast increase in hard substrate around the UK coasts. Recent legislation has put more emphasis on environmental and socio-economic benefits of coastal structures to minimise or mitigate ecological impacts. A guidance report for the Environment Agency as well as partner governmental bodies and developers has been produced with information and advice regarding ecological enhancement in the planning, design and construction stages of hard coastal structures (Naylor *et al.* 2011). Most of the methods outlined are still experimental, although some have been included in constructions as mitigation. The report describes methods of general and specific ecological enhancement. 'General ecological enhancement' includes practises such as arranging rocks in rock groynes to maximise void space for fish and invertebrates to utilise (Li *et al.* 2005). 'Specific ecological enhancement' is used for targeting particular species or habitat niches, such as building rockpools in vertical walls.

1.0.0.3 The perception of desirability or undesirability of effects of artificial structures in the marine environment are value judgements related to societal goals and expectations (Firth et al. 2013). The following management targets were identified (Burcharth et al. 2007): Provision of suitable habitat to promote living resources for exploitation of food (such as shellfish and fish), living resources that are the focus for recreational or educational activities (angling, snorkelling, rock-pooling, bird-watching), conservation of endangered or rare species and rocky substrate assemblages (biodiversity) for conservation or mitigation purposes.

1.0.0.4 The aim of this report is to investigate the ecological value the lagoon wall could provide and to suggest design measures that would benefit the ecosystem. We base recommendation to a large extent on the latest research on eco-engineering of coastal defence structures in the coastal and marine environment (Firth et.al 2012, and Bohn et al. 2013).

## 2.0 Artificial structures in the marine environment

2.0.0.1 Artificial structures like pontoons, piers, breakwaters or seawalls are increasingly common in coastal waters. While the primary objective is to protect areas from flooding or erosion, or modify hydrodynamics and sediment movement, these structures will be colonised, or 'fouled', by marine algae and fauna. Sessile marine organisms will settle on the firm, stable surfaces, and the artificial structures become new habitats for animals and plants (Ardizzone *et al.* 1989, Baine 2001, Bombace et al. 1994, Chapman & Bulleri 2003).

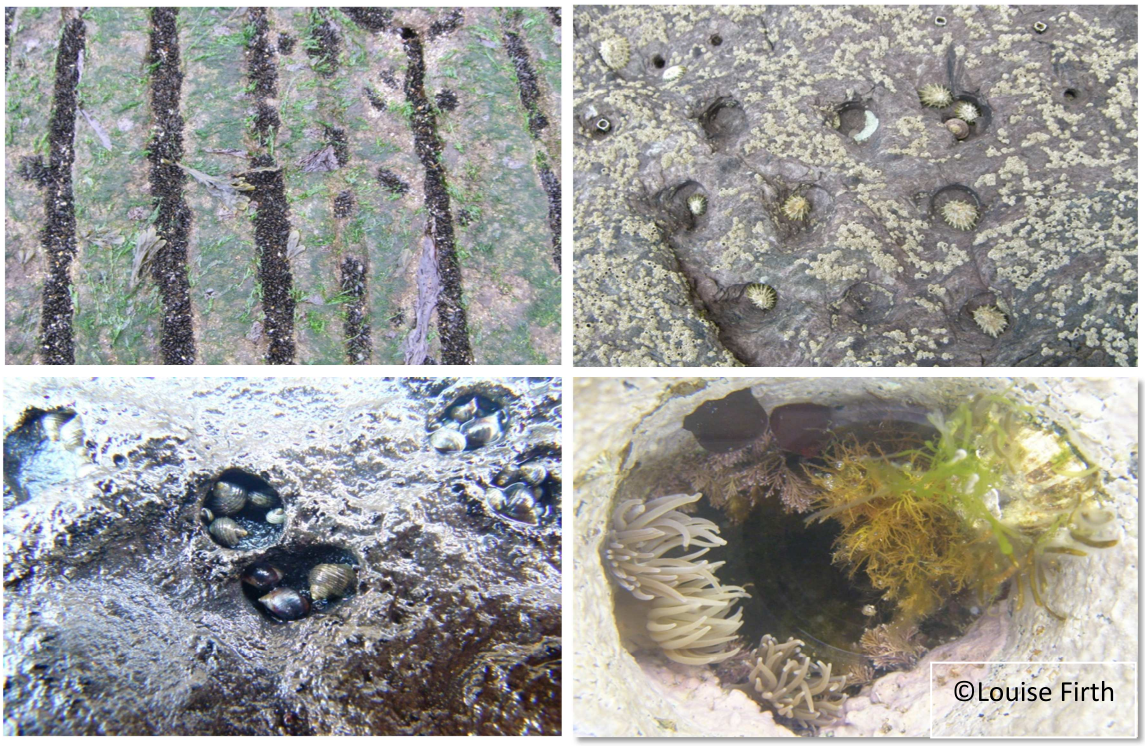


**Figure 1: Environmental heterogeneity: Roughness, crevices & pools**

2.0.0.2 Depending on the complexity of the man-made structures they have the potential to behave as artificial reefs, providing not only substrate for sessile organisms, but also shelter and protection for motile species such as fish and crustaceans. Generally, the diversity of the biotic community is directly linked to the diversity of the physical habitat, be it natural or artificial (Langhamer *et al.* 2009). Natural weathering and erosion in limestone, for example, can provide crevices and surfaces more suitable for marine organisms to utilise. On a micro-scale, geology and surface roughness have significant effects on the structure and functioning of the colonising assemblage, while on a small to medium scale, crevices, pits and rock pools provide important refuges for many species (Firth et al. 2013; Figure 1).


**Figure 2: Top row: *The Vicissitudes* by Jason deCaires Taylor. 26 life-size figures at 5m depth. Grenada, West Indies. [www.underwatersculpture.com](http://www.underwatersculpture.com). Bottom row: *Another place,* Antony Gormley – 100 life-size statues on the beach at Crosby, Liverpool, UK. These intertidal objects have become colonised by the invasive barnacle *Austrominius modestus*.**

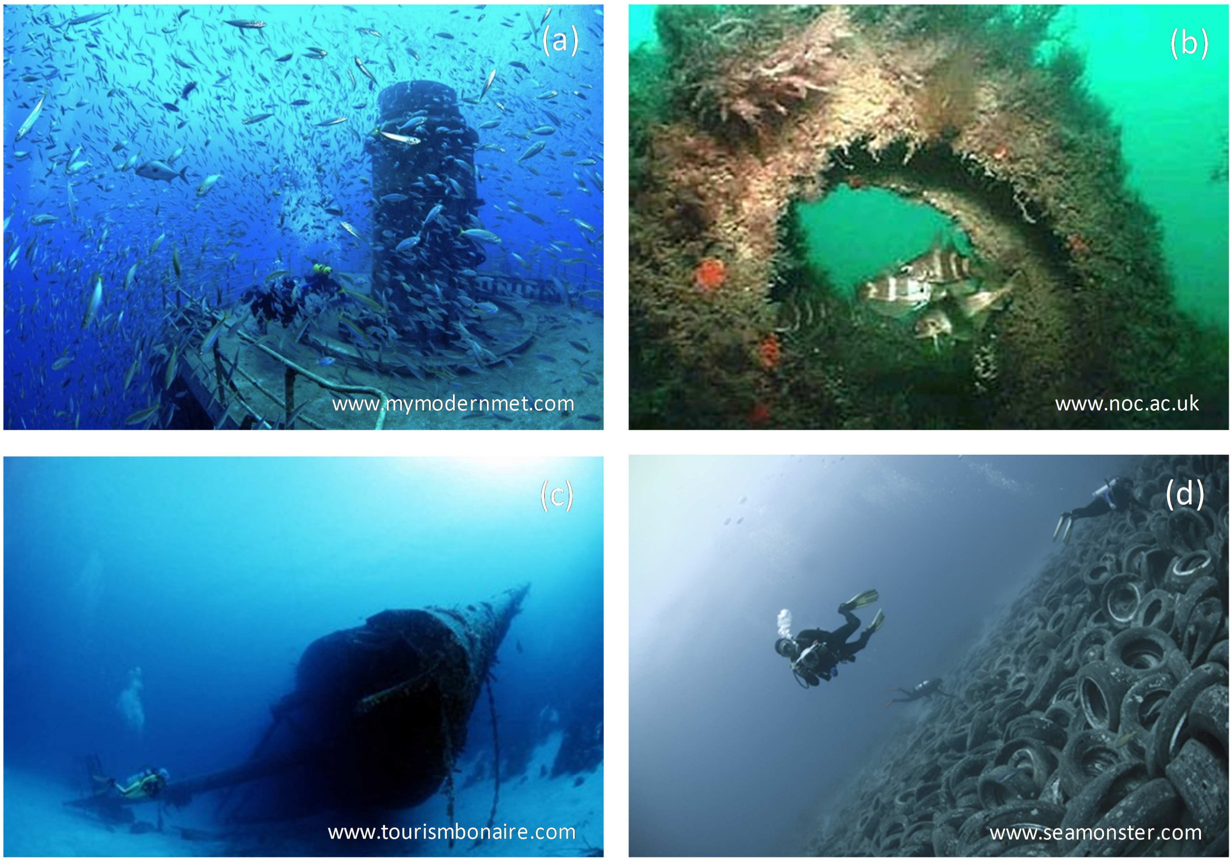


**Figure 3 (after Firth 2013). Artificial reefs provided by sunken ships and used rubber car tyres at (a) Key West, Florida, (b) Poole Harbour, UK (c) Bonaire, Dutch Antilles, and (d) Fort Lauderdale, Florida.**

2.0.0.3 The nature of the fouling community depends on the specific interactions between the artificial substrate and the local fauna and algae, and the biota of artificial substrata can differ from that associated with natural ones (Connell & Glasby 1999, Pister 2009). Hence, artificial habitats do not substitute natural substrate, but they potentially supplement the natural habitat by supporting naturally occurring marine species. Marine species do not differentiate between the purposes of artificial structures, which was exploited in several arts projects (Figures 2&3).

2.0.0.4 The proposed tidal lagoon walls are to be made from geotubes filled with dredged sand and from rock armour. The latter will provide hard substrate that will be colonised by algae and sessile invertebrates. The lagoon has the capacity to provide a habitat similar to natural rocky shore substrate (Naylor *et al.* 2011). Hard structures like rock rubble breakwaters are considered to have the greatest potential for ecological enhancement for species characteristic of intertidal rocky shores (Naylor *et al.* 2011).

## 3.0 Negative effects of artificial structures

3.0.0.1 Artificial structures are often built in sedimentary environments that lack rocky shores or other hard substrate. Assisted by the structure, species may colonise an area and get a foothold which would naturally not be the case. The artificial structures will provide stepping stones for the expansion and distribution of species. This may not be desirable. Warm-water species, for example, reached natural shores of the Isle of White by using artificial coastal defence structures as intermediate steps (Keith et al. 2011, Mieszkowska et al. 2006). Artificial structures also appear to be more susceptible to invasive species than natural habitats (e.g. Buschbaum et al. 2012). Individual species may be favoured with knock-on effects on communities which could differ from natural assemblages, and they may even influence the biodiversity of surrounding areas (Inger *et al.* 2009).

3.0.0.2 The proposed tidal lagoon would be situated in an area rich in natural and artificial hard substrate. While the lagoon wall would extend the provision of hard substrate, it seems unlikely that it would provide a new stepping stone for sessile organisms. However, some studies have found that artificial substrata had higher abundances of non-native species. Examples include the green alga *Codium* fragile in the Adriatic and the colonial tunicates *Botrilloides violaceaus* and *Botryllus scholosseri* in Maine, USA (Tyrrell and Byers 2007) in comparison to adjacent natural substrates. Around Swansea Bay, non-native species that feature in relatively high numbers include the slipper limpet *Crepidula fornicata* which competes with the native oysters *Ostrea edulis.* It is also feared that the Pacific oyster *Crassostrea gigas* may invade the Welsh coast and cause changes in the ecosystem similar to other European coasts (Diederich 2005). The lagoon structure would provide attachment material for this alien species, similar to natural hard substrate. Currently there is just anecdotal evidence of individual records of the Pacific oysters, and no significant numbers have so far been detected. We cannot foresee an increased risk of the Pacific oyster colonising Swansea Bay due the lagoon development, other than the additional provision of hard substrate.

3.0.0.3 It should however be considered that the existing rocky shores and artificial structures are already colonised, and that ecological processes such as competition for space and food by fouling organisms have taken place. The new surfaces will provide an opportunity for species to expand their population, and this process should be monitored carefully with the awareness that under favourable circumstances invasive species may take the opportunity to get a foothold.

## 4.0 Positive ecological effects of artificial reefs

4.0.0.1 The ecology of artificial coastal structures is often compared to that of natural rocky shores, being the closest equivalent in nature (Naylor *et al.* 2011), although communities on artificial hard substrate may be less diverse compared with adjacent natural habitats (Pister 2009). Importantly, artificial structures are often colonised by species that create their own habitat, such as kelp, mussels or honeycomb worms. As a consequence the artificial structure becomes host to secondary biogenic, reef-forming species which accelerate the development of a diverse algal and faunal community.

4.0.0.2 The intertidal zone is a challenging environment for marine organisms to live in. Hydrodynamic forces, emersion and fluctuations in salinity and temperature require rocky shore species to be well adapted to survive in harsh environmental conditions. Around the Bristol Channel the tidal range is high and intertidal animals and plants tend to exist in spatially discrete zones, determined by biotic and abiotic factors. The zonation pattern on the shore is predominantly determined by the tolerance of organisms to being out of water and exposed to terrestrial conditions. The higher up the shore, the longer the period of emersion and the greater the risk of desiccation. The inclusion of crevices overhangs and rockpools in the tidal lagoon wall will increase water retention, and such structures will enable some lower shore species to exist higher up the vertical gradient of the eulittoral zone. The subtidal part of the structure which is always covered by the sea can enhance commercially important species such as lobsters and crabs. These benefits could also be extended to other commercial species such as mussels (*Mytilus edulis*), and native oysters (*Ostrea edulis*).

## 4.1 Fish

4.1.0.1 Artificial structures in marine environments have the potential to increase diversity and abundance of fish and crustaceans. This has been shown for offshore structures ranging from wind turbines, wave power devices to oil jetties (Langham & Wilhelmsson 2009, Langhamer 2012). Positive effects can be found for fish such as cod, but particularly also for edible crab (*Cancer pagurus*) (Langham & Wilhelmsson 2009). The increase in fish and crabs may have negative knock-on effects for other fauna such as starfish, which are exposed to higher predation pressure (Langham & Wilhelmsson 2009). Positive effects on fish may not just be found comparing artificial reefs with soft bottom habitats, but artificial reefs may also attract a more diverse fish fauna than natural ones (Rilvo & Benayahu 2000). Benefits for fish may result from reefs being enhanced feeding grounds as well as shelter from predators, water movement and trawling. Rilvo & Benayahu (2000) suggested that artificial reefs also provide more successful recruitment grounds. In the longer term a spill-over of fish and invertebrates to other areas further afield would be of benefit to commercial fisheries (Langhamer 2012).

4.1.0.2 There are, however, also examples where artificial reefs had no effect on fish (McGlennon & Branden, 1994), and it is uncertain whether the increase in fish is ‘attraction’ or ‘production’. Ongoing discussions question whether artificial reefs attract and concentrate existing individuals, with no overall net increase in abundance, or whether they actually promote recruitment and the production of individuals, resulting in a net increase of fish or invertebrates (Brickhill 2005, Pickering & Whitmarsh 1997).

4.1.0.3 The variety of artificial reefs that have been studied is vast, making it difficult to assess and compare design aspects and performance as suitable habitats for fish and crustaceans. The difference in geographic location and localised environmental conditions will also have an effect on the species attracted (Baine, 2001). Low-crested coastal defence structures (LCS) may be the most appropriate comparison structure to the Tidal Lagoon Swansea Bay in terms of its construction design. Comparisons of LCS around Europe including the UK, Italy and Spain have identified the effects these structures have on sediments and mobile fauna. These structures have not been found to increase overall diversity in the area, but create a substrate for the development of local assemblages. LCS built in coastal areas dominated by soft substrata can have a strong effect in the structure of the fish community by attracting species typical of rocky shores, and thereby locally increasing diversity (Martin et al., 2005). The fish observed on the structures mainly consisted of juveniles and individuals no older than 2 years, so they do not perhaps offer appropriate habitats for adult fish populations. The accumulation of drifting algae around LCS was shown to indirectly enhance the settlement of fish and crustaceans. This algal detritus can be attractive to new settlers and juveniles of fish and crabs (Martin et al., 2005). Beside the natural accumulation of drifting algae that could occur around the outer wall of the tidal lagoon, small adaptations that mimic drifting algae could have a positive effect on the numbers of juvenile fish recruited to the area. One study found that artificial reef blocks with unravelled polypropylene rope streamers attached attracted significantly higher numbers of juvenile fish (Gorham & Alevizon, 1989). There is the possibility of achieving this with little cost in the way of materials and the labour involved to unravel the ropes and attach them around the structure. Biodegradable materials could be used instead of polypropylene; ropes made from coconut fibre (coir) could be a feasible option. Over time the walls will probably be colonised by macrophytes and will naturally produce drifting algae.

4.1.0.4 Large artificial reef units with varying complexity have been found to attract different compositions of fish species. In a study off the coast of France, reef units that had been filled with materials to increase complexity were found to attract different species of fish (Charbonnel, 2002). Fewer planktivorous fish but significantly higher numbers of commercial species were found in the more complex reef unit structures. The principals described for invertebrates are transferable to fish: an artificial structure that aims to increase fish biodiversity needs to be as heterogeneous as possible. Using a complex mixture of materials such as hollow bricks, concrete pipes etc., creates irregular and interconnected spaces that can be utilized by predatory and prey fish (Charbonnel, 2002). If the tidal lagoon aims to design part of its structure to become conducive to fish and crustaceans, the ecological requirements of the local species should be taken into account. More complex and heterogeneous structures will provide more shelter for fish and crustaceans , with high-profile structures attracting pelagic fish and low-profile, bottom reefs with extensive void space will attract mobile shellfish (Baine, 2001).

4.1.0.5 Langhamer (2012) pointed out that there is still significant research effort required to predetermine specifically the eventual advantages when creating new habitats and how they can affect commercially interesting species such as fish, lobsters and crabs. Aspects of the design of a structure to perform as an artificial reef will need to be influenced by the ecology and the behaviour of the target species (Polovina & Sakaie, 1989).

## 5.0 Design features of the lagoon wall: creating an artificial reef

5.0.0.1 The design of artificial coastal structures has a major effect on the natural environment (Firth et al. 2013). The magnitude of the effect appears to be heavily dependent on the nature of the created structure, the location and the composition of the native flora and fauna at the time the artificial structure is created. The structural complexity of the building materials and the architecture play an important role for the number and diversity of animals and plants colonising the artificial material, and hence whether an artificial structure will eventually qualify as a reef. Here we review design features that could be implemented in the construction of the tidal lagoon Swansea Bay. The role of the surface texture of building materials is explored, as well as the creation of artificial rockpools and the introduction of building blocks specifically designed to attract a range of colonising species.

**Figure 4: Habitat enhancement: drill-cored rock pools at Tywyn. (Firth et al. in press, Coastal Engineering, Photos L. Firth)**

## 5.1 Surface texture: ridges, overhangs and rockpools

5.1.0.1 By mimicking a rocky shore with a mixture of rock sizes, roughness and crevice sizes, then marine life can be encouraged to develop (Li *et al.* 2005). Incorporating porous, calcite rich materials can provide habitat for other organisms, especially rock boring species. This can improve the habitat by increasing the roughness of the materials via bioerosion, which will then be exploited by other species. Also, materials that have a variety of vertical and horizontal surfaces that retain water at low tide will encourage intertidal species to colonise (Naylor *et al.* 2011). Studies have shown that the gradient of substrate can furthermore affect species composition. Most naturally occurring rocky shores have a more gentle slope in comparison to artificial structures like sea walls. Studies have found that vertical substrates support fewer mobile marine organisms (Glasby 2000; Chapman & Bulleri 2003). Surface characteristics such as texture, complexity, size and even colour have been found to affect the numbers and types of organisms that colonise artificial substrates (Glasby 2000).

5.1.0.2 An extension of the modification of surface textures is the creation of artificial rockpools. These can be either attached to the artificial structure or they are excavated from the rock armour. Chapman and Blockley (2009) added experimental rock pools to a seawall, which attracted sessile and motile species, particularly in upper intertidal areas (Figure 4&5).

### 5.1.1 Outreach: Integrating science, artists and sponsorship

5.1.1.1 The artificial diversification of the lagoon wall would provide an opportunity to actively involve several groups of society and to integrate many interests. The shape and size of pits, ridges and crevices should primarily be diverse, and this could be exploited creatively. Artists could be given the opportunity to design modifications of the rock armour or to sculpture features that could be integrated into the wall. They could collaborate with ecologists in order to take colonisation patterns into account. Sponsors could apply for specific features to be carved into the rock armour. The modifications would also be an opportunity for scientist to test specific features such as standardised rockpools in a controlled manner.


**Figure 5: Habitat enhancement pioneers: Artificial rock pools on Sydney seawalls**

**Figure 6. Pre-fabricated reef blocks; a) Reefballs are used to promote biodiversity ([www.reefball.org](www.reefball.org)); b) BIOBLOCK (Firth et al. 2012)**

## 5.2 Precast reef blocks

5.2.0.1 A method to improve the structural complexity of an artificial reef is the deployment of precast units. These are designed to attract particular species or to offer multiple habitat types. A recent example is a collaborative project between SEACAMS Bangor, Conwy Council and Ruthin Precast Concrete (RPC). Bangor University have developed a large-scale habitat enhancement unit called the BIOBLOCK. The objective of the BIOBLOCK is to provide additional habitat types that can be incorporated into rock armour, breakwaters groines and revetments at the construction stage. The BIOBLOCK has rockpools, circular pits and longitudinal depressions.

5.2.0.2 “Reefballs” are based on a similar idea but are designed differently (Figure 6). Depending on the artificial environment and the enhancement unit in question, these can be deployed either during construction or retrospectively to effectively increase local biodiversity (Chapman & Blockley 2009, Firth et al 2013).

### 5.2.1 Outreach: design competition for precast reef blocks

5.2.1.1 TLSB is considering incorporating pre-fabricated reef-type modules into the lagoon wall and would be looking for the design that is particularly successful at attracting species in Swansea Bay. It is suggested that a public competition could generate a new design of a pre-cast module, or a number of different solutions may result from the competition. Various groups could be invited to the competition, for example engineering students, biology students, schools, investors, general public and artists. The event would strengthen stakeholder engagement and sense of identity with the lagoon. The most successful design would be produced and used in the lagoon wall.

## 5.3 “Shell BioReefs”- shell filled gabions

5.3.0.1 In recent years engineering solutions have been explored that prevent erosion of coastal habitats, and in particular the loss of sand and mud. In the Netherlands gabion cages filled with fished-up oyster shells were mounted on silt in intertidal areas. A continuous artificial oyster shell reef was created, 200 metres long and ten metres wide (Figure 7). Studies at Swansea University in collaboration the bioengineering company Salix showed that shell filled mesh bags attract a diverse coastal fauna within a short period of time, and they have the potential of enhancing local biodiversity. Shells could include cockle and mussel shells from local shellfish processors and restaurants, as well as dredged shell material from Swansea Bay from within the footprint of the tidal lagoon. The research is currently up-scaled to improve the construction of shell gabions and mattresses, improve their environmental sustainability, explore their effect on the surrounding environment and understand the longer term benefits for biodiversity. These shell bioreefs can potentially be tailored to specific needs of an artificial structure to maximise the environmental benefits.


**Figure 7: Shell filled gabions in intertidal areas to prevent erosion.**

# 6.0 Habitat features inside and outside the lagoon

## 6.1 'Mumbles Head' features

6.1.0.1 The area around Mumbles Pier inside Swansea Bay is recognised as a particularly biodiverse area. Oakley (2011) recorded 91 species in the intertidal area since 2004. It appears that the habitat properties in the area are suitable for many invertebrate, algae and fish species. It is generally a rocky area with much artificial hard substrate, and some of the habitat features could be copied for the design of the tidal lagoon area, particularly for the area outside the lagoon.

6.1.0.2 The intertidal area around Mumbles Pier is more sheltered than other parts of Swansea Bay since Mumbles Head provides protection from south-westerly winds. Habitats include boulder fields, shallow pools and mixed sands, but also man-made structures such as a disused sewerage pipes and legs and joists of the pier and lifeboat station. It appears that the man-made artificial substrates are particularly valuable for biodiversity, and naturalists and scientists emphasise that these structures should not be removed from the area, even if they are not used any longer (Oakley, 2011). Scientists from the Natural History Museum in London and universities around the country come to the Mumbles Pier intertidal area to sample less well known groups of species such as moss animals (Bryozoa) or sea slugs (Nudibranchia), which are reliably diverse on these shores. The pier is also a popular angling spot with anecdotal evidence of rare fish species regularly being caught here. Trigger fish are commonly reported as well as the protected Allis shad. The area is also colonised by invasive species regarded as less desirable members of the species community, such as slipper limpets or the leathery sea squirt. It provides evidence that a rich native fauna can integrate invasive species.

6.1.0.3 The tidal lagoon would not provide the man-made facets of the Mumbles Pier habitat, but it is feasible to copy the natural mixture of rocky and soft shore elements. It is recommended to carry out a detailed analysis of the Mumbles Pier area, separate the different habitat features and determine their individual contribution to the biodiversity of the area. Further, it should be analysed which area around the TLSB provides the most similar conditions to the Mumbles Pier area and could be engineered to provide similar benefits to the coastal ecosystem.

6.1.0.4 The approach could focus on creating suitable herring spawning ground. A wide range of substrates have been described for herring spawning grounds in the North-east Atlantic, ranging from coarse sand to rock, though all investigations show gravel to be present on at least part of the grounds and is regarded as the preferred spawning substrate. The eggs are 1.0-1.4 mm in diameter and adhere to the bottom, forming extensive egg beds that are often many layers deep, and eggs hatch in 10-15 days. It would be feasible to incorporate gravel into the ‘coastscaping’ of the area outside the tidal lagoon.

## 6.2 Creating biogenic reefs

6.2.0.1 In engineering terms biogenic reefs are also referred to as "soft" engineering solutions (Bohn et. al. 2013). They include saltmarshes, seagrass, oyster and mussel beds and tube-worm reefs. These features offer protection from hydrodynamic impacts, retain sediment and reduce erosion, but they also diversify the habitat.

### 6.2.1 Native oyster reefs *(Ostrea edulis)*

6.2.1.1 The restoration of native oyster reefs is an aspiration for nature conservation in Wales (Woolmer et al. 2011). This has proved to be a challenging target and several studies describe the feasibility and problems of the natural recovery of depleted oyster stocks (Laing et al. 2005). Challenges range from knowledge gaps in the ecology of oysters around Wales, e.g. the dispersal patterns of their larvae, to concerns about biosecurity of introducing oysters from outside. Swansea Bay is one of the centres of these discussions because of its well documented former oyster stocks and fisheries. In 2013 a local oyster company, Mumbles Oyster Company, announced a restoration program of native oysters in Swansea Bay and they have introduced live oysters at the Western part of Swansea Bay where the company holds a several order. Details and footage of the introduction of oysters in Swansea Bay can be viewed on the company's web page http://www.mumblesoystercompany.co.uk.

6.2.1.2 TLSB aspires to contribute to the recovery of oyster reefs. However, in contrast to introducing oysters from outside Wales with the purpose of developing an oyster fishery, TLSB is interested in optimising the numbers of offspring of native oysters from Swansea Bay. The aim is to create reefs undisturbed by fishing impacts, and instead focus on the promotion of biodiversity. The efforts would have knock-on benefits for the local oyster fishery by increasing the overall supply of oyster larvae and spat in the area.

6.2.1.3 The feasibility of utilising the tidal lagoon for rearing oysters was reviewed by SEACAMS (2013). The lagoon offers compelling benefits for oyster reefs. It provides shelter from wave energy which could, if unmitigated, displace juvenile oysters. This may increase the overall recruitment success. Oysters are also of commercial value and any created reef would face the risk of being destructed by poachers. Since the area of the tidal lagoon is closely monitored the risk of poaching is reduced.

6.2.1.4 There are several ways of re-introducing oysters, varying in the degree of methodological invasiveness. They range from promoting the settlement of naturally occurring larvae to relaying and on-growing of hatchery-reared stock. The most successful method of creating oyster beds would be the introduction of hatchery reared spat, as done by the commercial operator. This bears the risk of importing parasites and diseases into Swansea Bay. The tidal lagoon offers opportunities for a different, less invasive method. The proposed method is influenced by advice from cutting edge results of the recently concluded EU project *Oysterecover* (http://oysterecover.eu/), which provides guidelines created by European scientists and practitioners who worked collaboratively to establish the scientific bases and technical procedures and standards to recover the European flat oyster production. The core idea for the tidal lagoon is to use the oysters that currently inhabit the footprint area of the lagoon and artificially restrict the dispersal of their larvae. This will produce larger numbers of spat than would naturally occur, and the offspring would then be used to create oyster reefs.

6.2.1.5 The tidal energy lagoon wall offers opportunities for constructing spatting ponds. Conditions in these are artificial ponds stimulate the settlement of oysters (Gatheorne-Hardy and Hugh-Jones 2004, Laing et al 2005). Spat collectors inside the ponds encourage the attachment of oyster larvae during the breeding season. The method is used by the oyster industry in Cork Harbour, where ponds are stocked with 700-800 oysters which produce up to 50 million spat oysters for on-growing (Laing et al. 2005).

6.2.1.6 For the tidal lagoon in Swansea Bay it is considered to build ponds integrated into the wall or separately inside the lagoon area. There are known, rudimentary stocks of oysters in Swansea Bay, and these could be used to stock the ponds. Larval production and settlement success could be monitored. Current oyster stocks are low and the remaining population in Swansea Bay consists of relatively old individuals. Oysters within the footprint of the tidal lagoon will be dredged before the start of the lagoon construction and kept in CSAR facilities at Swansea University or re-located in Swansea Bay. Once the lagoon is built these individuals will be used to maximise the spatfall of Swansea Bay oysters. Larvae and spat will be either hatched in spatting ponds inside the lagoon or in laboratory facilities located on the lagoon wall. Juvenile oysters which settled on cultch material will then be transferred to areas inside the lagoon to grow on and eventually create a reef. Young oysters will also be placed outside the lagoon and performance in terms of survival, growth and impact on biodiversity will be monitored.

6.2.1.7 Associated with the core aims, the program offers opportunities for research on the biology and ecology of oysters and the ecosystem services of bivalve reefs. The success of establishing oyster reefs inside or outside the Swansea Bay Tidal Lagoon is uncertain, and similar attempts in other area suggest that it would be a long-term project. It is therefore prudent to be cautious about raising expectations of the outcome of such work. However, since the lagoon itself is a long-term project, it is a rare opportunity to attempt such an ambitious scheme, which, if successful, would add greatly to the value to the Swansea Bay Tidal Lagoon project. The table below outlines key steps in the process.

### 6.2.2 Work flow for creating oyster reefs in the Tidal Lagoon Swansea Bay

| | | |
|---|---|---|
| **Pre- lagoon construction period** | | |
| 1. | Removing oysters from within the footprint of the tidal lagoon by dredging the area with an oyster dredge. | The location of oyster grounds in Swansea Bay are broadly known and it is feasible to dredge them up in order to avoid their destruction during the lagoon construction phase. There is uncertainty regarding the exact numbers of oysters in the area, but stocks are generally rudimentary and consist of relatively old individuals (10yrs +). |
| 2. | Place oysters in hatchery or relocate within Swansea Bay | Trials in SEACAMS have shown that Swansea Bay oysters survive well under hatchery conditions within the Centre of Aquatic Research. The facility could be used to temporarily host the dredged oysters. Alternatively the dredged oysters could be relocated within Swansea Bay. |
| **Lagoon construction period** | | |
| 3. | Construction of ponds inside the tidal lagoon. | Spatting ponds shelter oysters from severe environmental conditions and can stimulate spawning. Closed pond systems will restrict the dispersal of larvae and promote larval settlement. |
| 4. | Constructing a hatchery and laboratory at the tidal lagoon | The hatchery facility will allow producing oyster spat in a controlled environment. Factors such as temperature and algal food supply can be optimised. |
| **Post-lagoon construction period** | | |
| 5. | Stocking spatting ponds with oysters that were dredged from within the footprint of the tidal lagoon prior to construction | Oysters stored in CSAR will be relocated to the spatting ponds. |
| 6. | Optimising the spatting conditions in ponds | The successful production of offspring from oysters in spatting ponds underlies many variables. It is site specific and depends on the condition of the oysters. The process needs to be trialled and optimised. |
| 7. | Optimising the spatting conditions in hatchery | The production of spat in hatcheries is a well-documented process. However, the physiological condition of oysters differs and the process has to be trialled and optimised. |
| 8. | Creating oyster reefs from offspring generated in spatting ponds or hatchery | The aim is to stock 3-5 discrete areas inside the lagoon with oysters from the spatting ponds and/or hatchery. The exact location depends on sediment and hydrodynamic conditions within the lagoon. It is anticipated that there will be suitable subtidal areas, |

| | | |
|---|---|---|
| | | but possibly also intertidal areas; in Swansea Bay native oysters are naturally found in lower intertidal areas, although in low numbers.<br><br>In order to create control areas, it is aimed to stock a similar number of sites outside the lagoon. |
| 9. | Monitoring of created oyster reefs | The growth and survival of oysters inside and outside the lagoon will be monitored. |
| 10. | Assessment of biodiversity of created reefs | The extent to which the created oyster reefs support biodiversity compared with other habitats will be assessed. Invertebrate fauna, algae and fish will be monitored. |
| 11. | Academic research linked to created oyster reefs | TLSB seeks to undertake research in collaboration with Swansea University to address current knowledge gaps. With regards to oysters this could be questions regarding their impact on water quality and algal composition, effects of harmful algal blooms (HABs) or climate change related issues such as ocean acidification (OA) and the calcification of shells. |
| 12. | Development of strategy to contribute to oyster restoration programs | The development of a method that utilises a tidal lagoon for the creation of oyster reefs will depend on a series of experiments and optimisation stages. Each stage may have to be adapted to site specific conditions, technical feasibility and nature conservation requirements. However, the longevity of the tidal lagoon allows a step-by-step adaptive process and TLSB aspires to develop a procedure that can be transferred to other lagoons or similar structural developments. If successful the method could be rolled out to assist oyster restoration programs in other areas. |

### 6.2.3 Honeycomb worm reefs (*Sabellaria alveolata*)

6.2.3.1 The main benefit of Sabellaria reefs is their function as 'ecosystem engineers': they provide a habitat for other species, thereby supporting a wide variety of invertebrates. They support a higher diversity of species than surrounding sandy areas (Dubois *et al.* 2002). It is for this reason that they are a protected feature under the EC Habitats Directive.

6.2.3.2 *Sabellaria alveolata*, the honeycomb worm, may benefit from the presence of the tidal lagoon walls. The tube worm is generally found in lower intertidal and shallow subtidal areas with relatively strong water movement. Initially larvae of *S.alveolata* settle on firm substrate such as rock, pebbles or bivalve shells. They construct firm tubes by cementing sand grains together, and the first step to a reef is generally a veneer of tube aggregations covering the settlement substrate. The firm worm-tubes then provide settlement substrate themselves for future generations, creating a self-promoting, sustainable system, which can result in substantial reefs. Artificial coastal defence structures have been found to provide settlement substrate similar to natural materials and were found to be colonised by large numbers of *S.alveolata* (Firth et al. 2013, Frost et al. 2004).

6.2.3.3 In the vicinity of the proposed site of the Tidal Lagoon, the honeycomb reef worm *S.alveolata*, is present in the intertidal area to the east and west of the River Tawe. A previous CCW report states that the area of *S. alveolata* found within the Swansea Local Biodiversity Action Plan (LBAP) area is 69.47 ha (Brazier *et al.* 2007). Preliminary studies by Swansea University confirm the importance of the tube-worm for biodiversity in Swansea Bay: comparisons between sandy areas, intertidal boulder fields and Sabellaria aggregations indicated that Sabellaria reefs were by far the most diverse habitat and supported a wide range of invertebrate species.

6.2.3.4 During the construction of the tidal lagoon in Swansea Bay some of the Sabellaria reef would most likely be destroyed, particularly the reefs within the footprint of the lagoon. TLSB proposed to rescue the reef by moving it to a nearby position not affected by the construction work. There is ongoing pilot work at Bangor University attempting to transplant Sabellaria that were reared and settled in the laboratory, but to our knowledge physically relocating existing reefs would be a novel approach. It would certainly be an interesting but challenging attempt to minimise environmental impact, and we would be cautious about the success of such a measure. Like other coastal invertebrates *Sabellaria alveolata* has specific habitat requirements such as food supply and a preferred current regime, and subtle changes may render a location unsuitable. However, if substantial blocks of reef could be moved to areas Swansea Bay which are already colonised, and which are in the vicinity of the original location, then successful re-location is plausible. Further, if the worms themselves would not survive the move, the rigid tube structures are generally robust and would survive at least for some weeks or even months, depending on the exposure to hydrodynamic forces. The worm-free tube aggregations would still allow colonisation by other invertebrates, and they would promote biodiversity. The tubes would also enable juvenile Sabellaria larvae to settle and rejuvenate the reef. However, generally this approach would be experimental and the feasibility needs to be explored. The SEACAMS project could assist with the necessary research.

### 6.2.4 Seagrass

6.2.4.1 Seagrass meadows are declining at an unprecedented rate (Waycott et al. 2009, Orth et al. 2006), therefore the ecosystem services they provide are also at risk including their role in fisheries production, biodiversity provision and nutrient cycling (Cullen-Unsworth et al. 2013). In Europe and the UK, land reclamation, coastal development, overfishing and pollution over the past centuries have nearly eliminated seagrass meadows, with most countries estimating losses of between 50-80% of the original area. Seagrass was once abundant and widespread around the British coasts, but serious declines have occurred, in particular as a consequence of a severe outbreak of 'wasting disease' in the early 1930s (Davison and Hughes 1998). Recovery of seagrass beds in the UK since the 1930s has been slow and patchy, and both Zostera species are now considered nationally scarce in the UK suggesting restoration is a key priority. In Wales seagrass meadows are currently in a poor and degraded state with an unknown but significant amount of loss thought to have occurred historically, locations such as Swansea Bay may have historically contained seagrass prior to the Industrial revolution. In the early

1990's sporadic isolated patches of intertidal seagrass (Zostera noltii) was recorded in the Blackpill area of Swansea Bay.

6.2.4.2 Seagrass restoration technology still remains in its infancy, however sufficient advances now mean that restoration projects have the potential to be highly successful if techniques are used that consider the whole ecosystem and its capacity to be restored. Current knowledge of restoration of the common UK species Zostera marina favour establishing genetically diverse meadows through a combination of techniques based around the collection of seeds from donor meadows, their direct distribution, and their grow out as seedlings for planting. Extensive discussions with leading restoration scientists from around the World confirm these findings, and indicate that restoration in the UK is possible. The UK Biodiversity Action Plan for seagrass beds specifically details the restoration of 1000 hectares of seagrass during 1997-2010. Transplantation trials using limited seagrass expertise in the 1980's and early 1990's were carried out around the south coast of England, but with little success in the long-term. No seagrass in the UK has been restored to date.

6.2.4.3 Swansea University and Salix Bioengineering are currently undertaking a collaborative project through SEACAMS to investigate the potential to conduct restoration in the UK. To date, this project has successfully harvested and stored seagrass seeds with a view of growing these in the laboratory for planting during 2014 and 2015. The project is utilising the restoration knowledge developed in the USA by the Virginia Institute of Marine Sciences (VIMS) and published within the scientific literature (Unsworth and Bertelli 2013).

6.2.4.4 The proposed tidal lagoon area in Swansea Bay will potentially create an environment of high shelter (low wave action) and contain sandy and muddy substrate, conditions potentially appropriate to seagrass. If water clarity becomes higher within the lagoon due to the reduced influence from the River Tawe and the River Neath then light availability could become sufficient to support seagrass growth. The lagoon area therefore has the potential to provide an opportunity for biodiversity enhancement through the creation of seagrass habitat.

6.2.4.5 For seagrass habitat creation to be a viable in the lagoon, modelling of the underwater light environment would be required to determine that light availability levels were sufficient. This would require verification after construction. Support from NRW would be required in order to assist with seed collection from other sites in Wales.

## 6.3 Further opportunities to create multi-species systems

6.3.0.1 This report outlines a number of suggestions to create a species rich, diverse artificial reef. The list of ideas should however not be regarded as closed and many other projects could be developed. We summarised mainly conservative, tried and tested ideas that would almost certainly achieve the desired effect. However, the tidal lagoon is a unique project which would offer unprecedented opportunities to trial and research new approaches for the restoration and creation of habitats. The lagoon area would, for example, provide opportunities to study systems similar to Integrated Multi-Trophic Aquaculture (IMTA). The term describes the co-culturing of species for environmental and economic benefit. Generally, these systems include species which are fed or intensively farmed (for example Atlantic salmon) are grown alongside species whose culture results in nutrient (or energy) extraction (for example sea urchins, mussels or seaweeds). The aims are greater efficiency in resource use: feedstuffs, space, labour and a reduction in the environmental impact of the aquaculture process. Waste products from one species are used as input (fertilizers, food) for another. The principals of IMTA could be transferred to multi-species systems created in the lagoon.

6.3.0.2 We recommend that TLSB continues to collaborate with scientists and aquaculture specialists to explore these novel opportunities.

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