UNDERSTANDING THE BENEFITS AND LIMITATIONS OF COASTAL NBS

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As Coastal NBS are implemented more widely it is important to be clear in our definition of NBS and understand the benefits and limitations of the various approaches. Coastal NBS involve using natural features to offer, or improve, coastal protection while producing additional economic, environmental and social benefits. There are, however, a broad range of solutions spanning the creation of large expanses of habitats, hybrids of habitats and harder engineered structures and ecological enhancements of existing infrastructure. Costs and performance therefore vary widely and not all NBS are low cost or self-maintaining. In many instances the capacity for sedimentary habitats to self-maintain will depend on sediment availability and this emphasizes the need to consider whole life costs when comparing NBS with more traditional harder defences. The incorporation of habitat components can however bring multiple benefits for both nature and people. Implemented correctly, Coastal NBS therefore have the potential to be 'no regret' solutions in many locations.

Keywords: nature-based solutions; sea wall enhancement, multiple benefits

INTRODUCTION

Over the last decade there has been an upsurge of interest in using coastal habitats as coastal defences. Many terms are used to describe these types of solutions including Green Infrastructure, Living Shorelines, Ecological Engineering, Natural and Nature Based Features (NNBF) and Nature Based Solution (NBS). This paper uses the term Coastal NBS as a convenient description for these types of solutions.

In the broadest sense, Coastal NBS involve using natural features to offer, or improve, coastal protection while producing additional economic, environmental and social benefits. Coastal NBS solutions are attractive since they potentially offer a number of benefits in terms of lower whole life cost, ability to self-maintain and as well as other benefits associated with recreating or restoring coastal ecosystems (e.g. recreation, well-being, fisheries, water quality carbon sequestration).

As we begin to implement Coastal NBS at a larger scale, it is important to be clear about what we mean by NBS and also to understand the benefits and limitations of various approaches and thus there suitability for different settings. Without this clarity the risk exists that projects will fail to live up to stakeholder expectations, leading to disappointment at a local level and making it more difficult to promote and implement NBS more widely in the future.

This paper:

- Provides a definition for NBS in their widest sense
- Explains what coastal NBS are proposes a simple classification system
- Takes a critical look at several examples from around the world

NATURE BASED SOLUTIONS

At the highest level NBS can be defined as:

'actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits'.

This definition comes from International Union for the Conservation of Nature (IUCN; Walters 2016). In this context, societal challenges include climate change, natural disasters, social and economic development, human health, food security, water security, ecosystem degradation and biodiversity loss.

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NBS can be applied to a variety of contexts including coastal, estuarine, riverine, and terrestrial locations. In these different setting they can provide solutions to a range of issues such as: flood & erosion risk management, water quality improvement, storm water management, carbon sequestration, and sunshade provision. NBS can be distinguished from habitat restoration projects in that they involve deliberately using the functions provided by habitats to tackle problems beyond biodiversity loss alone. This paper is focusses on NBS in coastal settings.

COASTAL NBS

Overview

Coastal NBS use natural features to achieve one or more of the following:
- Reduction in flood or erosion risks directly – either by reducing waves and water levels or by reducing erosion and stabilise sediments.
- Augmentation of the function of an existing hard defence – for example by reducing the size of the defence or reducing its maintenance requirements.
- Creation of additional environmental benefits through the provision of various ecosystem services such as water quality improvement, fisheries improvement, carbon sequestration etc.

A range of Coastal NBS approaches exist including:
- The re-creation of natural habitats (e.g. saltmarshes, mangroves, reefs, beaches, dunes).
- The enhancement of existing habitats (e.g. foreshore recharge of beaches).
- The use of more organic materials for structures (e.g. wood rather than stone).
- The ecological enhancement of existing hard infrastructure (e.g. creation of rock pools within seawalls, or the use of textured concrete to improve colonization by marine organisms).

Coastal NBS can be used alone or in combination with structures to form hybrid solutions (e.g. foreshore recharge, marsh restoration and embankment construction).

An historic perspective

Although Coastal NBS is a relatively new term, the role of natural habitats, in mediating risk has been recognized by coastal engineers for many hundreds of years (Williams *et al.,* 2016). Early engineers recognised the role that a full beach could play in providing protection to a seawall, with the concept of groyning to hold a beach dating back to at least the last 1800s in the UK, and the beginning of the 1600s in the Netherlands (Williams et al., 2016). The risk reduction capacity of other habitats, such as marshes and mangroves, occurred more recently (late 1950s; Salgado and Martinez, 2017).

Writing in the mid 2000's, Reeve *et al*. (2004) stated that a wider recognition of the coastal regime and its processes led to the adoption of breach renourishment, artificial headlands and offshore breakwaters from the early 1970's onwards. In the UK coastal management community, the term 'soft engineering' became common parlance from around the 1980s to describe these type of solutions. Reeve *et al.* (2004) noted that there was:

'a marked trend towards 'soft engineering' rather than the traditional hard concrete structures that were considered in the past'. The same authors also noted that '*Soft engineering does not exclude hard structures but describes the more holistic approach to coastal and flood defence…*' a perspective that is similar to the 'multiple lines of defense' concept that has been more recently promoted by the United States Army Corps of Engineers (USACE) and others (e.g. USACE, 2023; Lopez, 2009)

Regardless of history, there has been an undoubted increase in interest in NBS after the Indian Ocean tsunami in 2004, and various events in the US including Hurricane Katrina in 2005 and Hurricane Sandy in 2012 (Pontee *et al.,* 2017).

The take-away message from this brief history lesson is that whilst some NBS might be new, others have been deployed for decades or centuries and thus and are therefore relatively well understood.

There are two important perspectives for considering Coastal NBS:
1. Protecting existing natural habitats to safeguard the coastal protection services they provide.

2. Incorporating habitat elements in new or replacement defences to gain the additonal benefits that they provide over and above traditional hard defences.

In this paper we are concerned mainly with the second of these perspectives.

A SPECTRUM OF SOLUTIONS

In this paper Coastal NBS are classified as three broad types:
1. Expansive – solutions that create large new expanses of habitats
2. Hybrids - solutions that involve some harder components as well as habitats
3. Enhancements - solutions that involve enhancing or 'greening' existing hard defences

Type 1 – Expansive solutions. These solutions create of large expanse of habitats to reduce wave energy and water levels. The type of habitat that is created depends on the geographic region being considered and the habitats that naturally occur there. In temperate latitudes, appropriate solutions might involve large expanses of dunes or even gravel berms. In tropical or subtropical locations, mangroves or even coral reefs might be more appropriate (Figure 1). Critically, these solutions require large amounts of space which is not always available in heavily urbanised areas. If finding sufficient space involves moving the shoreline seawards, then solutions are likely to be more costs effect where water depths are shallower. Space permitting, such solutions can be deployed in estuarine or coastal locations.

Figure 1. Example of Type 1 Coastal NBS – Expansive. The Sand Motor in the Netherlands. This project is a mega scale beach renourishment project. The project placed 21.5 million m^3 of sand in a hook-shaped peninsula of 128 ha, including a dune lake and a lagoon. Following construction in 2011, the sand has indeed spread along the coast, with coastal accretion both to the south and the north. Photo credit: Rijkswaterstaat/Jurriaan Brobbel.

Type 2 - Hybrid solutions. These solutions involve grey/hard elements and green/more natural elements. These solutions use structures to either:

- maintain or enhance existing habitats and together provide flood risk reduction; or
- to guarantee sufficient protection against high water levels.

Such solutions commonly include harder structures such as nearshore or shore-attached breakwaters designed to reduce wave energy and thus lessen erosion and promote accretion. In the US such structures are often referred to as living shorelines and are commonly designed to allow their colonization by oysters and are thus termed oyster reefs (Figure 2). The reefs may be made of rock, concrete blocks, or bags of oyster shell. Other hybrid solutions include the creation of stable bays between artificial headlands created by the replacement of rock amour or the construction of saltmarsh in front of flood embankments.

Figure 2: Examples of Type 1 Coastal NBS – Hybrid. Nearshore reefs to reduce marsh erosion. Photo credits: The Nature Conservancy. Right image. Oyster reefs constructed from bags of oyster shells

Type 3 – Enhancement solutions involve the enhancement of existing grey/hard/traditional structures and can take several forms including:

- Adding textured surfaces and water retention features to existing sea walls to encourage colonization by algae and encrusting organisms (e.g. recasting textured units for incorporation during construction or by adding bolt on tiles for retro fitting
- Adding precast rock pools within rock revetement
- Adding vegetation to the front of defences by creating terraces (see Greenwich Peninsula example below).

Further information on enhancement solutions can be found in Naylor *et al.* 2017 and the Living Seawalls project (https://www.livingseawalls.com.au/).

CASE STUDIES

Compared to traditional solutions hard engineered solutions Coastal NBS can:

- Create additional habitats
- Offer multiple other benefits (co-benefits)
- Offer financial savings
- Be naturally adaptive (through vegetative growth and sediment trapping)

However, these benefits do not automatically apply to all Coastal NBS – they vary depending on the setting and the solution chosen. The following section presents several case studies that span a variety of different NBS.

Each case study details:

- The name of the project and its location.
- The objective of the project e.g. flood reduction, erosion reduction.
- An explanation of the type of NBS.
- The alternative traditional harder engineered solution.
- The additonal benefit that the NBS solutions delivers.
- The cost of the NBS relative to a traditional harder engineered solution.
- The degree to which the NBS self-maintains.
- Sources of further information.

Alkborough Flats Flood Storage, Humber Estuary, UK

Objective: To reduce extreme flood water levels in Humber estuary.

Solution: A flood storage area that fills rapidly during flood events and lowers water levels in the inner and middle region of the estuary (Figure 3).

Classification: Type 1 – Expansive.

Detail: A 440ha low lying site located approximately 60 km from the estuary mouth (Figure 4). The site is designed to fill rapidly under surge tides with water spilling into the site over a 1.5km weir. A 25m breach allows regular tides to indicate a smaller part of the site to lower levels. New setback defenses were constructed to limit flooding further inland. The project was completed in 2006.

Alternative to: Raising flood embankments throughout a wider reach estuary.

Additional benefit: The managed realignment component allows the site to flood more regularly through a breach allowing the creation of mudflat, saltmarsh and brackish marshes. At the time of construction the total annualized benefit for ecosystem service benefits (excluding flood defence benefits) was estimated to £0.9M (Manson, 2017).

Cost relative to alternative: NBS project cost was £11.1M (2006 prices), which was approximately £12M less than the cost of raising the flood embankments throughout inner and middle reaches of the estuary (Manson, 2017).

Self-maintaining? The earth embankments have no capacity to self-adapt. The intertidal areas within the scheme have the potential to accrete sediment and develop and maintain vegetation – but over the long term this reduces the storage volume for flood waters and thus reduces the effectiveness of the scheme.

Further information: Wheeler e*t al.* (2008) and Manson (2017).

Figure 3. Location of Alkborough Flood Storage scheme in the inner Humber estuary at the confluence of the Rivers Trent and Ouse.

Figure 4. Oblique aerial view of the Alkborough Flood Storage scheme in the Humber Estuary, UK. Photo credit: the UK Environment Agency. The dotted line delineates the project area. The flooded fields indicate the intertidal compartment which is regularly flooded through a small breach at the downstream end of the site (see arrow).

Monmouth Dunes, New Jersey, USA

Objective: To reduce coastal erosion and flooding.

Solution: The restoration of beach and dunes to dissipate wave energy and prevent ocean waters from flooding inland areas (Figure 5)

Classification: Type 1 - Expansive.

Detail: A one-mile long dune system along the Atlantic Ocean, built by beneficially reusing 50,000 cubic yards (40,000m^3) of dredged material. The project was initiated after the area was severely impacted by Superstorm Sandy. The project was completed in 2016.

Alternative to: Seawall, offshore breakwater.

Additional benefit: The dunes were designed and constructed to provide nesting habitat for endangered species and together with the fronting beach also provide a valuable recreational resource for people.

Cost relative to alternative: The project was funded by a $1.78M National Fish and Wildlife (NFWF) Coastal Resiliency Grant. This covered the design and construction of the Monmouth Beach dunes plus the restoration of marsh islands within the Shrewsbury River. The construction costs of the dunes was cheaper than a conventional seawall, but may require more maintenance (rebuilding) over the long term due to renourishment requirements.

Self-maintaining? Likely to require periodic renourishment following erosion in severe storms.

Further information: National Fish and Wildlife Foundation and US department of the Interior (2019).

Figure 5: Monmouth dune and beach restoration involved the placement of 40,000m3 of sediment which was planted with marram grass plugs.

Arlington Cove Living Shoreline, Alabama, USA

Objective: To create new oyster habitat and promote marsh regrowth.

Solution: A small scale oyster reef project comprising five reefs.

Classification: Type 2 - Hybrid.

Detail: The five reefs were situated approximately 100 feet (30m) from the shoreline. They were constructed from 2,375 'oyster castles^{TM}' concrete blocks placed by 340 volunteers Figure 6. Design work included: the review of existing data including wind, waves, bed sediments and geomorphology; topographic and bathymetric survey; a wave climate study; options appraisal; reef design and permitting. The project was constructed in 2015.

Alternative to: rock breakwater, marsh edge protection.

Additonal benefit: Creation of new oyster habitat.

Cost: Low. $125,000 including installation by volunteers (Figure 6).

Self-maintaining? The reef has the potential to self-maintain. The development of oysters should increase the connectivity of the individual concrete elements and, overtime, the growth of new oysters should raise the elevation of the reef helping it keep pace with sea level rise. The regrowth of the saltmarsh will depend on the availability of sediment.

Further information: The Nature Conservancy (2023).

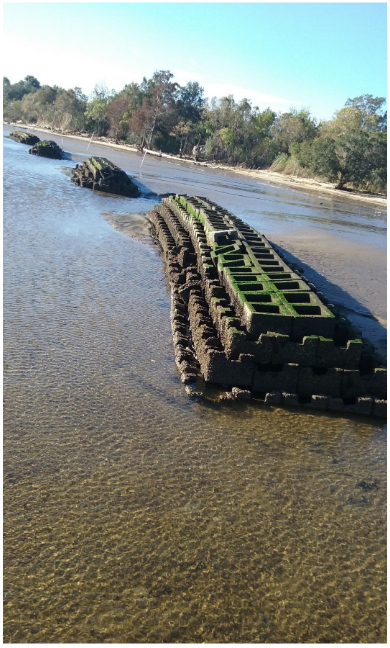

Figure 6: Arlington Cove oyster reef (above) under construction – a total of 370 volunteers paced over 2,375 concrete blocks to produce five nearshore reefs (right).

Greenwich Peninsula, London, UK

Objective: To replace a sheet piled retaining wall.

Solution: Set-back defences and a vegetated platform (Figure 7).

Classification: Type 2 – Hybrid & Type 3 - Enhancement.

Detail: A new L-shaped concrete wall was installed inland of the existing sheet pile wall and capped with concrete. The existing sheet pile wall was cut down to varying heights to create intertidal terraces. The truncated piles had a concrete wall inserted immediately behind them to ensure stability and were capped with timber. In some areas intermediate terraces were created between the new wall and the foreshore using gabions for the lower terraces and wooden piles for the higher ones. The sediment fill was initially protected under coir matting and the areas were planted was conducted with a variety of saltmarsh plants. The project was constructed in 1997.

Alternative to: Online replacement of piled wall.

Additional benefit: Creation of additonal vegetated intertidal habitat.

Cost: Lower than rebuilding the original sheet piled wall to its full height.

Self-maintaining? In theory the vegetation on the terrace is self-maintaining. However, in reality, wave action at the site led to lifting of the matting and erosion of many young plants in the first year after completion. This necessitated some replanting although a considerable amount of natural colonization did also occur. Failure to install rhizome breaks within the sediment led to excessive dominance of the terrace by Common Reed. As sea levels rise in the future it may be necessary to add additonal sediment to raise the elevation of the terraces and this prevent the vegetation from drowning under increased tidal inundation.

Further information:Estuary Edges (2019) and Naylor et al., (2017).

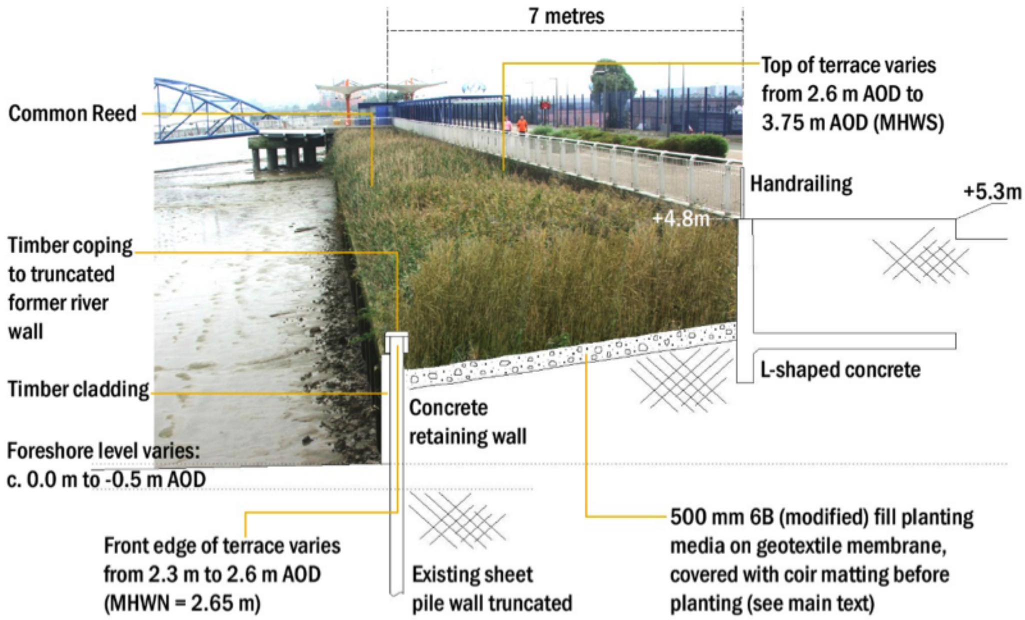

Figure 7: Eastern Wall (north end) Greenwich Peninsula, London. The image was taken in autumn 2003, six years after construction. Photo credit: the UK Environment Agency (Estuary Edges, 2019).

Tyndall AFB Resilience Study, Florida, USA

Objective: To reduce flood risks arising from SLR and hurricanes.

Solution: Multiple approaches including dune, beach and marsh renourishment, oyster reefs and other more traditional defence solutions (Figure 8).

*Classification:*Type 1 – Expansive and Type 2 - Hybrids (i.e. systems of defences comprised of NBS and more traditional approaches).

*Detail:*Following extensive damage associated with a major (Category 5) hurricane which made landfall in the northern Gulf of Mexico coastline in 2018, Tyndall Air Force Base (AFB) required rebuilding to achieve higher levels of resilience to high wind and flooding, whilst also being environmentally and socially sustainable. Initial work showed that NBS were both economically viable and could offer an enhanced level of protection and performance compared to other alternatives. Dunes on the Tyndall peninsula, barrier island beach/dune enhancement and marsh enhancement were all part of the best performing options, delivering both flood risk reduction benefits and a range of additional environmental, amenity, and other benefits. A follow-on study to develop a base wide resilience plan undertook a more detailed evaluation of assets at risk and the available solutions. This work concluded that over the longer term a range of flood risk management measures were needed including property level measures, conventional levees in addition to NBS.

Alternative to: Floodwalls and levees alone.

Additonal benefit: Habitat for endangered species and recreational use by base personnel and the public.

Cost: Variable depending on the NBS being considered. Some NBS such as sand fencing to increase dune height were relatively low cost, whilst others such as dune construction using imported sand were more costly.

Self maintaining? The development of vegetation on dunes likely to improve their sand trapping ability and improve their resistance to wave erosion. Dune and beach renourishment NBS are likely to require periodic renourishment following erosion in severe storms.

Further information: Pontee *et al.* (2023)

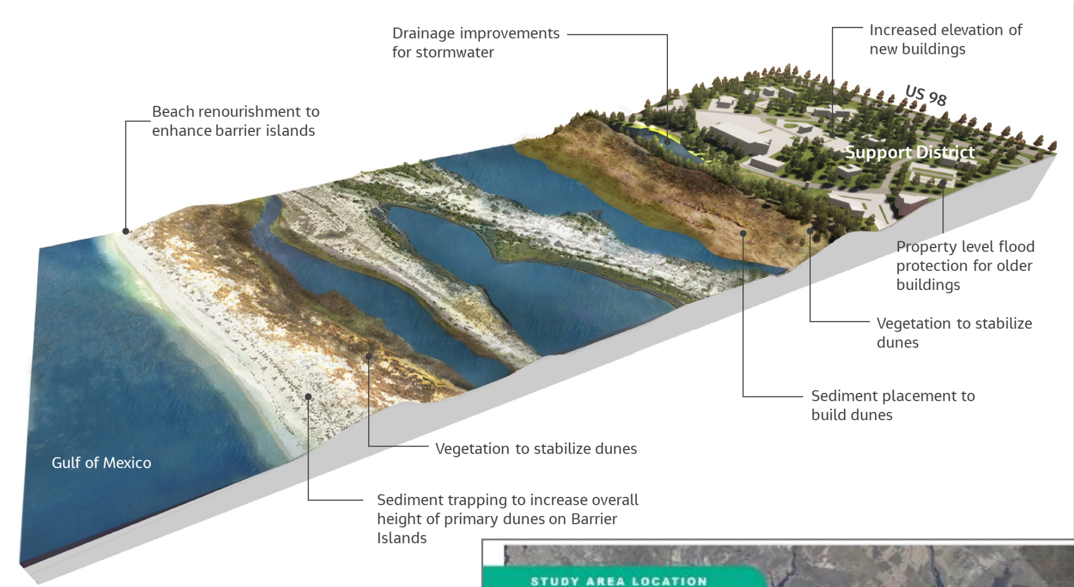

Figure 8: Tyndall Air Force Base in the panhandle of Florida. The base is located on peninsula large parts of which lie at low elevations and are vulnerable to flooding. The long-term strategic resilience pan for the AFB includes multiple types of flood risk management solutions.

CONCLUSIONS

This paper has demonstrated that the Coastal NBS banner covers a broad range of solutions. This range of solutions means that costs and performance vary widely and are dependent on the solutions chosen, individual designs and geographic setting. Importantly not all NBS are low cost or self-maintaining. Large scale beach renourishment projects or dune construction project are likely to have significant costs. The establishment and development of vegetation on dunes or salt marshes is likely to enhance sediment trapping and resistance to erosion. However, how much sediment is trapped and the resulting morphological response of the habitats strongly depends on the availability of sediment in the surrounding environment as well as the hydrodynamic exposure of the site. Severe storms, especially on sandy coasts are can lead to significant losses of sediment either alongshore, offshore or onshore, and periodic maintenance campaigns may be needed. This is to be expected and the concept on ongoing maintenance is one also that applies to hard defences. Options appraisal studies comparing NBS and hard defence structures therefore need to consider whole life costs, and not just construction costs. Regardless of differences that exist between the different types of Coastal NBS, one clear advantage is that the incorporation of habitat components can bring multiple benefits for both nature and people (van Zanten *et al.,* 2021 and Guerry *et al.,* 2022). Implemented correctly, Coastal NBS therefore have the potential to be 'no regret' solutions in many locations.

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