Greening the Grey:

a framework for integrated green grey infrastructure (IGGI)

University of Glasgow

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1. INTRODUCTION

A quarter of 53 respondents in a recent survey of engineering and environmental practitioners indicated that improved guidance and case studies on the costs and benefits of different forms of green infrastructure would help wider uptake (Naylor et al., 2016). In response to this need, this report identifies the opportunities, economic costs, wider benefits and risks of approaches to construction and development that seek to 'green' elements of 'grey' infrastructure. It collates a range of innovative 'green-grey infrastructure' projects from the UK and elsewhere that showcase opportunities for wider application.

The report is based on a business case model that compares green-grey options with 'business-as-usual' solutions in a range of coastal, urban and historic settings. This approach aims to provide evidence and economic justification that can be used to make a stronger case for implementing green-grey solutions more widely. The report is targeted at a range of practitioners and end-users including developers, infrastructure providers, local authorities, national agencies, public bodies, asset managers and local community groups.

Greening approaches to fluvial engineering are addressed in a separate, complementary report (see HR Wallingford 2017: 'Green approaches in river engineering: Supporting implementation of green infrastructure').

1.1 GREEN INFRASTRUCTURE – A CONTEXT

The concept of Green Infrastructure (GI) has shown strong growth over the last decade. Within flood risk management, focus has been placed on minimising intervention by **working with natural processes** (Environment Agency, 2017) through which some forms of green infrastructure can be achieved. At a European level, the concept of **nature based solutions** is often used as an umbrella term and covers use of GI elements that seek to achieve small-scale local benefits up to tackling larger-scale social issues of flooding, climate change and poverty (European Commission, 2015). Much of the drive to implement GI comes from the recognition that natural elements in cities (and beyond) provide a range of **ecosystem services** (ES) for people, usually grouped into provisioning, cultural and regulating services (DEFRA, 2013). Using GI to maximise provision of these services is a key aim in innovation and application. In urban areas, ecosystem services provided by GI can include reducing flood risk, cleaning air and water, ameliorating extreme weather, and supporting resilience of ecosystems and biodiversity to environmental change.

A large amount of information regarding GI application and benefits (environmental, social and economic) is now available, and GI concepts are increasingly incorporated into national guidance and policy (Table 1.1). These have primarily focused on improving the ecological function, biodiversity value, and social value of existing land and water resources rather than the built environment itself (Naylor et al. 2014). Focus has been placed on the spaces around buildings (parks, urban trees etc.) or to other well-established forms of greening such as green walls and roofs on buildings. In comparison, opportunities for greening other types of hard (i.e., grey) infrastructure assets such as freestanding and boundary walls, transport networks and bridges are not yet widely considered. Where opportunities to green these assets are identified (e.g., EC, 2012) there is little or no guidance on what can be achieved or how to do this effectively. Other types of policy could be used to integrate green grey infrastructure, examples are listed below in Table 1.2 but this list is not exhaustive.

Table 1.1 Green infrastructure, environment and planning policy which could be extended to include IGGI.

Green Infrastructure	Planning
• Benefits of Green Infrastructure (2010)- Forest Research CIEEM (2016) • Cities, Green Infrastructure (2015)- Landscape Institute • Demystifying Green Infrastructure (2015)- UK Green Building Council • Green Bridges Guide (2015)- Landscape Institute • Green Infrastructure Guidance (2009)- Natural England • Green Infrastructure Guide (2008) – North West Think Tank • Green Infrastructure in Urban Areas (2011)- RICS Green Infrastructure: Connected + Multifunctional landscapes (2009)- Landscape Institute • Multifunctional Green Infrastructure (2012) - Science for the Environment Policy, European Commission • Multifunctional Urban Green Infrastructure (2010)- CIWEM • Trees in Hard Landscapes (2014)- Trees and Design Action Group • Trees in the Townscape (2012)- Trees and Design Action Group • Urban Green Infrastructure (2013)- Houses of Parliament	• Council Directive 2000/60/EC (WFD) (2000)- European Commission • Council Directive 92/43/EEC (Habitats Directive) (1992) - European Commission • Minimum Standards for Open Space (2005)- Scottish Government • Open space strategies Best practice guidance (2009)- CABE • Planning for a healthy environment (2012)- Town and Country Planning Association, Royal Society of Wildlife Trusts • Strategic Scoping Report for marine planning in England (2013)- Marine Management Organisation • The National Pollinator Strategy (2014)- DEFRA • UK Marine Policy Statement (2011)- HM Government

Table 1.2 Other policies that can potentially be used to implement IGGI

Economic	Nature, wildlife and ecosystem services	Social	Climate and flood risk regulation
• Economic Benefits of Greenspace (2012) Forestry Commission (Saraev) • Green Infrastructure Contribution to Economic Growth: A review (2013) - EFTEC, Sheffield Hallam • Microeconomic Evidence for the Benefits of Investment in the Environment (2012)- Natural England • Microeconomic Evidence for the Benefits of Investment in the Environment 2(2014)-	• Council Directive 2000/60/EC (WFD) (2000)- European Commission • Council Directive 92/43/EEC (Habitats Directive) (1992) - European Commission • Ecosystem services in a changing world (2013)- Raffaelli & White • The National Pollinator Strategy	• Community Green: Using local spaces (2010)- CABE • Green space Design for health and wellbeing (2012)- Forestry Commission (Shackwell and Walter) • Health, wellbeing and open space (2003)- OPENSpace • The evidence base for linkages between GI, public health and economic benefit (2015)	• Air temperature regulation (2013)- Forest Research (Doick and Hutchings) • Climate Change (Scotland) Act (2009)- Scottish Government • Estuary Edges Guidance (2008)- Environment Agency • Greater working with natural processes in flood & coastal erosion risk management (2012)-

Natural England • Natural Capital Investing (2015)- GI Task Force • The Green Book: Appraisal and Evaluation in Central Government (2003, 2011 update) - HM Treasury	(2014)- DEFRA	- Bowen & Parry • The Value of Public Space (2004)- CABE Space • Well-being of Future Generations (Wales) Act (2015)- Welsh Government	Environment Agency • Working with Natural Processes- Evidence Directory (2017)- Environment Agency

Full references for these policies are provided in Chapter 5.

1.2 INTEGRATED GREEN-GREY INFRASTRUCTURE (IGGI)

The term 'integrated green-grey infrastructure' (IGGI) is used in this report to refer to greening of hard infrastructure that cannot be replaced with softer green (or blue-green) solutions including transportation infrastructure, boundary walls and public infrastructure such as benches and railings (Naylor et al. 2014, 2017). IGGI therefore sits between entirely 'green' and entirely 'grey' options along a continuum of engineering approaches (Figure 1.1) and in simple terms is 'greening the grey'.

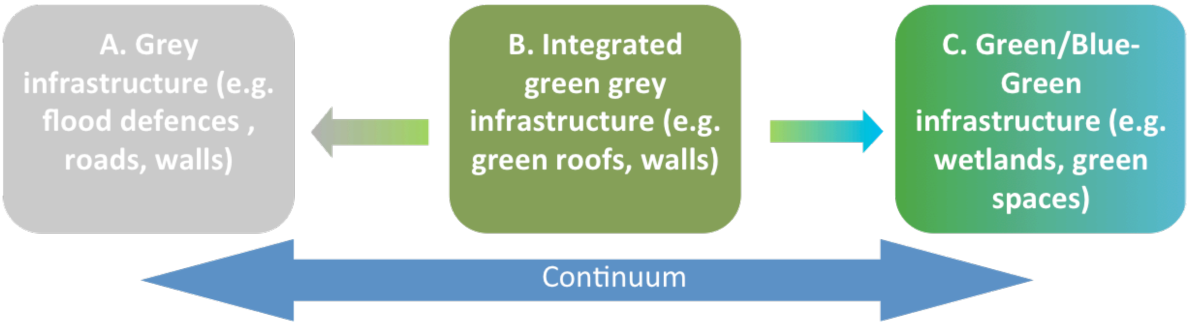


Figure 1.1 A continuum of infrastructure engineering approaches

A good example of where a green-grey approach is required is coastal flood and erosion alleviation infrastructure. Although there is a growing trend towards greener, nature-based approaches to flood and erosion risk alleviation (Environment Agency, 2017), in many urbanised locations traditional hard engineering approaches are adopted as nature-based approaches are often not socially, technically or economically feasible. In these cases, alternative approaches to 'green the grey' can be used to improve the multifunctionality and ecological value of hard coastal and estuarine infrastructure. The IGGI measures in this report can be used to help greening those grey assets that must remain primarily grey including flood alleviation and erosion control structures (including seawalls) as well as transport infrastructure, boundary walls and street furniture (Figure 1.2).

This report does not cover types of urban greening that are already well established or are covered extensively elsewhere, including GI in open blue and green spaces, Sustainable Urban Drainage Systems (SuDS), and green walls and green roofs on buildings.

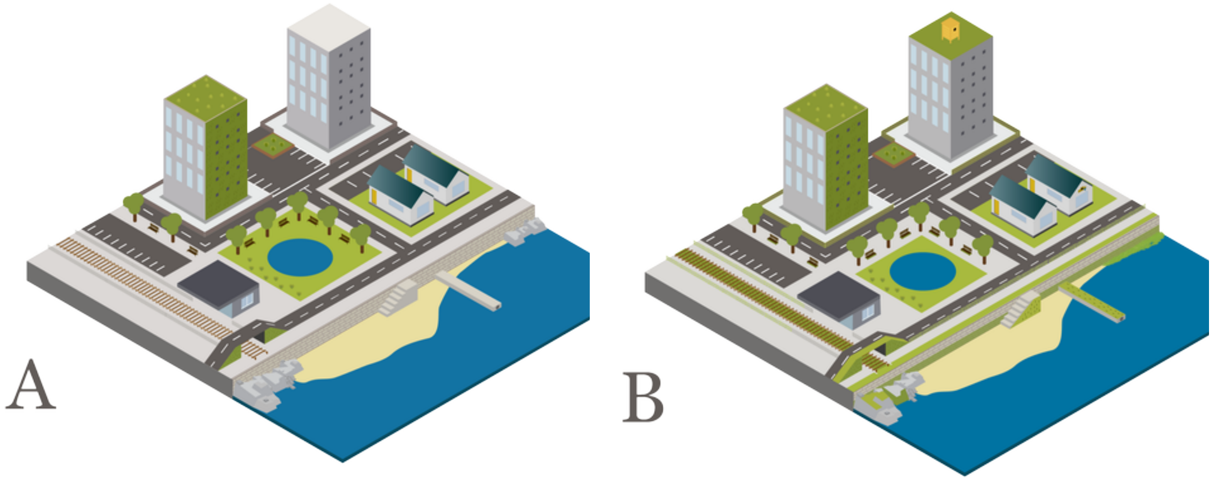


Figure 1.2 Examples of opportunities for 'greening the grey' where A: shows the types of GI currently covered in GI policy and practice and B: shows the potential additional greening that IGGI measures and solutions can provide.

1.3 THE BENEFITS OF IGGI

The social and environmental benefits of GI are increasingly well known (see sources in Tables 1.1 and 1.2). Equally, the examples described in this report show that IGGI solutions can provide ecosystem services in a range of settings, including ameliorating impacts of short-term flooding, urban heat and air pollution, and supporting biodiversity conservation. This aligns with many large organisations seeking to put biodiversity at the forefront of environmental commitments, including Highways England, National Rail and some local authorities. 'Good practice principles' for achieving biodiversity 'net gain' have also been developed for the wider construction industry (CIEEM, 2016), which IGGI can support. Greening of grey assets further provides opportunities to complement related targets and policies set out in, among others, Biodiversity Action Plans, Green Infrastructure Plans, Living Landscape plans, and Strategic Nature Areas.

Application of IGGI ideas has been facilitated by policy such as environmental impact assessment, the Habitats Directive, and corporate social responsibility. In doing so, IGGI approaches reported here have been successful in securing planning approval, winning public support and levering federal/national funding. Incorporating green elements into a greater range of built assets also offers opportunities for tackling social problems of health and well-being in urban areas. For example, IGGI can support local and national plans which regularly identify a need to achieve increased access open spaces, greenspaces, and green-blue spaces.

Despite these opportunities, the biggest barrier to wider uptake of greening of grey assets is uncertainty over (1) economic cost and (2) impacts on engineering performance, inspection and maintenance. By providing detailed information on costs, benefits and risks of already implemented IGGI examples, this report demonstrates that greening can not only provide a range of social and environmental gains, but that this can be achieved relatively cheaply with, very often, negligible impact on asset function. This report provides the tools and examples needed to support a business case for applying GI principles to those hard, non-building infrastructure assets that have typically been overlooked.

By broadening the range of assets for which greening is considered, more opportunities to achieve a range of economic, social and environmental benefits will be created. By drawing together examples of IGGI innovation and by providing a comprehensive economic assessment of different options, this report provides the evidence-based framework needed to enable wider uptake of greening.

1.4 REPORT STRUCTURE

Chapter 1 (this chapter) gives a broad context of GI and IGGI and illustrates some of the key issues and opportunities for implementation. It outlines the structure of the report and introduces some key terminology.

Chapter 2 outlines the IGGI measures and solutions that are included in each bundle.

Chapter 3 outlines the decision-making process. It presents a tool that can be used at a strategic level to identify wider implications of any IGGI solution applied as part of new schemes, on-going maintenance or retrofit activities. Importantly, it demonstrates how costs and benefits were calculated for IGGI options compared to business-as-usual options.

Chapter 4 introduces the factors felt to be critical to IGGI projects and an increased uptake. The chapter details how these critical success factors were identified and how they can be assessed for individual schemes and strategic assessments of historic, urban, coastal and historic environments, or at landscape, national or international scales.

Chapter 5 contains the Bundles – collated suites describing the business cases for each classification – a consideration of why IGGI measures may be of value in that field, with respect to relative drivers, cost benefits and possible outcomes. The bundles collate case studies and examples across four themes - Historic, Urban, Mowing and Coastal. Detailed case studies are based on existing examples of the IGGI technology in the field, drawing on evidence gathered as part of a relevant study, PhD work or similar. Less detailed examples can be found in the 'Art of the Possible' vignettes – these show similar examples of IGGI measures in alternative settings, and illustrate how these innovations can be implemented elsewhere.

2 IGGI MEASURES AND SOLUTIONS COVERED IN THIS REPORT

This report presents IGGI measures from four different environments found in peri-urban to urban areas (Figure 2.1). These environments were selected in close discussion with the project partners and were designed to draw in examples from fields such as coastal ecology, biogeomorphology and heritage conservation that can usefully enrich green infrastructure policy and practice. Importantly it covers urbanised parts of our built environment such as coastal and historic assets that are typically overlooked in GI policy.

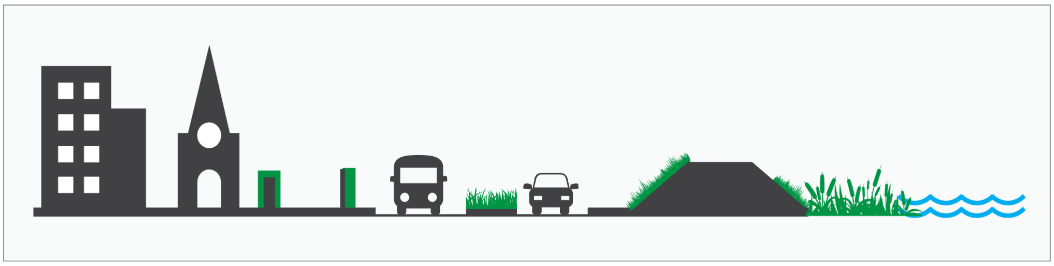


Figure 2.1. Illustration the range of environments covered by the report.

The integrated green grey infrastructure (IGGI) examples are the primary outcome of this project and are packaged into four main **topic bundles** (Appendices 1-4). The 'bundle' format was developed by project partners and practitioners who wanted to have the majority of suitable examples for each environment covered in a single document, along with the reasoning behind implementing these types of measures. For those working for local authorities, developers, statutory bodies, and other larger scale landowners, the bundles provide a one-stop shop to support measures on a landscape scale – and provide evidence-based support to aid wider implementation of a range of integrated green grey infrastructure alternatives to traditional, hard engineered solutions. The bundles are as follows:

Historic bundle: examples of greening of either historic grey assets or grey assets within historic conservation areas. This including old boundary walls, historic buildings, monuments and ruined sites.

Urban bundle: examples of greening of urban grey assets including temporary planting in urban spaces and construction sites, boundary walls and railings.

Mowing bundle: examples of managing grassed assets (earth embankments) for improved biodiversity and social amenity that can be applied in urban, historic and coastal settings (Figure 2.2).

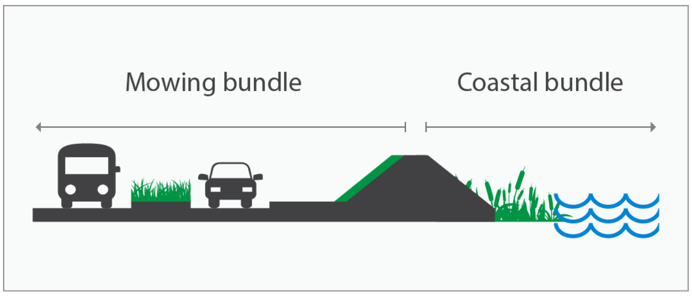


Figure 2.2 Diagram showing which environments the mowing bundle covers

Coastal bundle: examples of greening of coastal and estuarine grey assets including seawalls, breakwaters, jetties and walkways, revetments and outfalls.

Each bundle consists of a **Business Case** (BC) supported by several **Case Studies** (CS) and '**Art of the Possible**' (AP) examples (Figure 2.3):

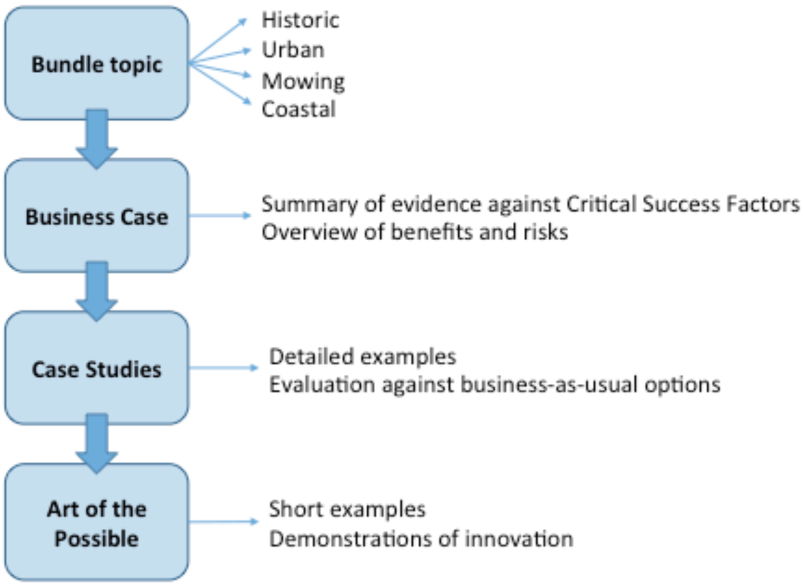


Figure 2.3 Overview of the structure of each 'bundle' used in this report

Business case: Describes the type and scope of the innovations in each environment, how they have been applied, where and when. It sets out a summary of all the evidence complied for each topic bundle. It provides an overview of the different IGGI measures showcased as case studies and 'Art of the Possible' examples (see below). This is based on eight **Critical Success Factors**: economic costs, ecosystem services, engineering, policy, data quality, social, reputation and asset resilience (see Chapter 5 for a full explanation of Critical Success Factors). Each Business Case considers: where IGGI measures have been applied so far; the contexts in which they may be applied elsewhere including physical, engineering and ecological context, and; the limitations and risks involved in their application.

Case studies: Detailed examples provided by a range of project partners (including academics, national agencies and private firms) that have sufficient data to enable assessment against each of the Critical Success Factors. Each case study is compared to grey ('business-as-usual') options. This approach is designed to help decision-makers budget more effectively, and to determine where cost-saving or cost-neutral IGGI options may be possible. Detailed accounts of the potential additional benefits to the environment, the local community and to businesses are provided to help to strengthen a case for application in other situations.

Each case study contains a data quality table that indicates the robustness of the supporting evidence, and sources of further information and key contacts.

Art of the Possible: Shorter examples that do not have sufficient supporting data for full evaluation (e.g., those at early stages of development or which have not yet been tested in practice) but which demonstrate innovation that could be considered in other situations. In the urban bundle only, there are also bite-sized art of the possible examples providing short summaries of IGGI measures that have been built but for which no or very limited data were available.

2.1 EXAMPLE IGGI MEASURES

For each bundle, IGGI measures were grouped into broad types to help cluster examples provided based on the types of infrastructure that IGGI has been deployed on and/or the environmental context of the IGGI measure. Each measure represents a specific type or installation of an IGGI approach which have been applied individually. These are summarised for each topic in Figure 2.4 below. Each case study (CS) and art of the possible (AP) included in the report is labelled by environment, e.g. Historic Case Study 1 is labelled as CS-H1 and Historic Art of the Possible 1 is labelled as AP-H1. The number of case studies and art of the possible measures included in this report varies between environment, this is based on the data that was provided through various requests for data from project partners, key practitioner and academic networks, as well as generated from webinars and events attended during the project.

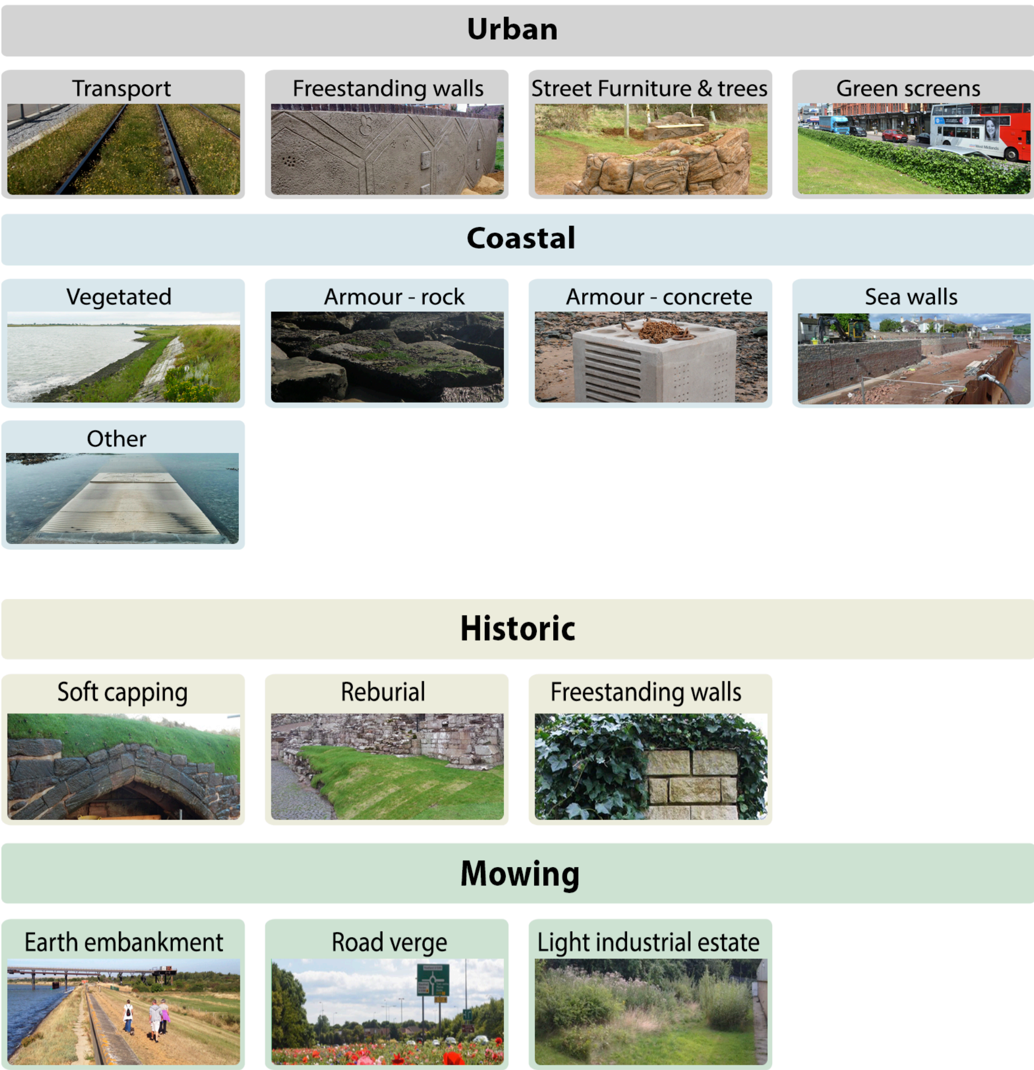


Figure 2.4 Summary of the different groups of IGGI measures which are included in each of the four environments covered in this report. Photo credits are listed in Appendices 1-4.

2.2 IGGI SOLUTIONS

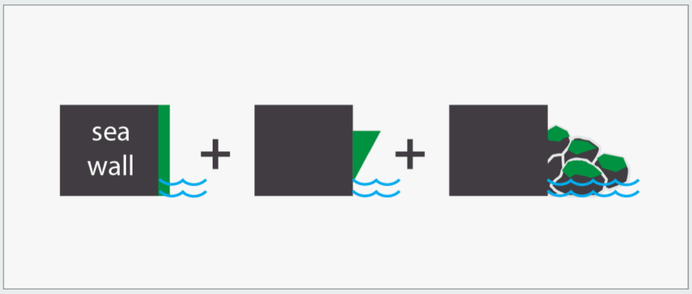
Individual IGGI measures can be grouped as IGGI 'solutions' where individual IGGI measures can be combined, or used in combination with other more nature-based forms of greening such as GI and working with natural processes approaches to reducing flood risk. Each topic bundle contains a full list of IGGI measures and identifies potential IGGI solutions. For example, the IGGI solutions can be used, in combination with more conventional GI approaches, across the landscape as part of strategic GI planning by landowners or government agencies. Some possible combinations of IGGI interventions, referred to as 'solutions' are illustrated here:

Example 1. An estuarine town with some architectural heritage might develop a strategy to ameliorate traffic-generated pollution while improving resilience *and* aesthetic appeal to tourists and locals - a 'solution' or collection of IGGI measures might include:

- Soft capping of historic walls to reduce the degradation of the stonework.
- Green screening of urban railings or street furniture to help trap and remove pollution.
- Altering mowing regime on verges and sea defences to improve the look of the town.
- Coastal salt marsh generation to improve flood resilience.

Example 2. Coastal: Multiple IGGI measures combined at a single location, e.g. sea wall – a traditionally flat, uniformly grey, poor substitute for a natural rocky shore. By combing;

- Textured sea wall (cast in a textured form liner).
- Retrofitted pocket rock pools, e.g. Vertipools.
- Textured rock placed to create maximum habitat and water retention.



The above examples illustrate how a traditional grey engineering solution can be enhanced to provide variety of complex habitats and support a broader diversity of species helping support urban ecosystem service provision.

3 INCLUDING IGGI IN DECISION-MAKING PROCESSES

Most engineered or manufactured environments could be adapted to include habitat, to some degree. The limiting factor in including it is, perhaps, not the lack of an IGGI option, but the drive to do it and the potential returns. Anecdotal evidence suggests sometimes IGGI measures can be scoped out when they are considered an additional asset that requires maintenance but there is no capacity in the budget to cover this.

IGGI measures have been used in every stage of a project; in early planning processes (as mitigation to offset potential impacts) or integrated at the construction phase, or as alternative maintenance or repair practices. Other measures provide opportunities for retrofitting into existing schemes and the examples in the Historic Bundle show how well certain IGGI measures can perform as retrofits on historic monuments and ruins.

The case studies and 'Art of the Possible' examples in this guidance (see Chapter 7) highlight a variety of opportunities for including IGGI in the decision-making process. Importantly, these examples illustrate how different measures can be used across an asset's timeline from pre-planning, commissioning and design, through to construction and completion right and then through its working life, including maintenance and repair events to decommissioning and beyond.

3.1 STRATEGIC LEVEL (SCALE)

Including IGGI at a strategic level can provide the framework that supports the inclusion of individual measures at a local scale. Like traditional GI, IGGI can be 'designed-in' as part of strategic planning and policy (e.g. Metro Vancouver, 2015). This can be particularly valuable in strategic attempts to meet specific targets, with combinations of measures, referred to here as 'IGGI Solutions' collectively helping address problems of air pollution across an urban borough, for example, or address flood risk across a watershed.

Potentially IGGI measures can be adapted for inclusion within a wide range of schemes, as illustrated by the 'Art of the Possible' examples. Some approaches will better suit large-scale projects or be more relevant across a landscape scale than more local measures; key considerations include:

- IGGI can be designed in as part of strategic planning and policy
- IGGI solutions (i.e. suites of measures) can be identified to help meet particular targets for GI, air quality, working with natural processes (the flood risk example) or ecosystem services (e.g. London Ecology Masterplan).
- The strategic scale can provide the framework that supports inclusion of individual IGGI measures at the local scale.

A good example of a strategic approach to urban greening that includes elements of IGGI is the London Ecology Masterplan developed by Arup and the Crown Estate, as described in Box 3.1 below. IGGI measures can also be usefully included as part of strategic estuarine and coastal flood risk strategies such as those being developed for the Thames and Humber estuaries. These strategic approaches to flood risk allow opportunities to identify IGGI measures and solutions, and to include key performance indicators to include them as part of strategic planning. For example, these strategic plans can recommend working with natural processes and use of IGGI measures wherever possible when meeting cost, engineering, policy and/or ecological requirements.

LONDON ECOLOGY MASTERPLAN

'Through a holistic estate-wide approach, the Masterplan provides a long-term, flexible strategy for enhancing landscape and ecological value through the delivery of multi-functional green infrastructure features that provide a range of ecosystem services. It links green spaces with new features to create a green corridor through the site'

London Ecology Masterplan Case study (Landscape Institute, 2017)

The Masterplan is underpinned by the innovative inclusion of ecology within the buildings environmental performance assessment method - UK BREEAM (Building Research Establishment Environmental Assessment Method). The London Ecology Masterplan was developed to enable the crown estate to more efficiently and effectively deliver their BREEAM requirements. This led to the development of a Strategic Ecology Framework (SEF) to evaluate and improve the ecological performance of buildings and other infrastructure assets in the Crown Estate's holdings. The SEF is used instead of annual BREEAM assessments for the assets within the Masterplan and aims to support decision makers/ project teams to:

- understand the existing ecology of a site to identify the best approach,
- identify, protect and enhance key ecological features,
- remove or limit existing features that are negatively affecting the site's ecology,
- mitigate unavoidable impacts and compensate against residual impacts,
- enhance the ecological value of the site and surrounding areas by encouraging ecological features.

The Masterplan targets planting of UK native species, where possible, to maximise biodiversity gains. Non-native species are selected where they provide a known ecological benefit e.g. a foraging resource.

One of the first project's arising from the Masterplan is to green the Crown Estate's St James Palace and Regents Street portfolios. By selecting those species of trees, shrubs and flowers with known ecological benefits, the rooftops, walls and the streets of the portfolios will encourage a range of wildlife species into the centre of London. This has been named, 'Wild West End' and many other property owners are now joining in the project to green one of the greyest parts of central London. IGGI measures in this report can be used to support this award-winning endeavour.

Box 3.1 Strategic scale GI including IGGI elements in central London.

3.2 SCHEME SCALE

At a scheme scale, there are three categories of intervention that can be adopted: 1) new or replacement build, 2) on-going maintenance activities and/or 3) retrofit. Many of the examples presented in this report have been tested or implemented in one form – such as during maintenance, but could be readily applied in all three intervention stages.

3.2.1 NEW BUILD

Though the client brief, site characteristics, and subsequent design and budget limitations will influence what is ultimately possible, new build projects can offer the widest possible opportunities to include IGGI. Strong business cases that address the risks, costs, benefits and opportunities can aid approval of IGGI approaches. Reference to successful examples, such as the case studies presented in this report, can help in supporting IGGI inclusion.

3.2.2 ON-GOING MAINTENANCE

The inclusion of IGGI can positively influence maintenance regimes, such as via cost savings. Initial use of IGGI measures has been driven by some organisations' attempts to reduce maintenance costs (e.g. reduced mowing budget necessitating a move from mowed grass to wildflower meadow). Even where IGGI measures are more costly than the business-as-usual model, IGGI measures merit consideration in decision making where they can provide enhanced resilience and/or reduce the need for interventions in the medium and longer–terms. Many of the examples presented involve simple changes in maintenance procedures that are cost neutral.

3.2.3 RETROFIT

Sometimes the driver to add IGGI measures may be a local, corporate or national policy change, and/or efforts to ameliorate a problem or potential problem. In these instances, retrofitting of IGGI measures has been used to improve social cohesion and/or improve ecological outcomes.

3.3 THE DECISION SUPPORT TOOL

3.3.1 OVERVIEW

This project has developed a decision support framework that is designed to help guide practitioners through the process of considering IGGI measures as part of an engineering or development scheme. This framework has been developed in coordination with the project partners and with HR Wallingford, who developed a similar framework. It is designed to sit within the five point business model context used by central government and aims to support decision makers in evaluating if IGGI measures can be applied within their new build, replacement or large-scale maintenance projects.

The process is circular and iterative where decisions made, and measures implemented are monitored and modified if needed using an adaptive management approach (Figure 3.1). The essential wider decision-making remains the same at each iteration of the process, including determining a need to take action and in assessing the strengths, weaknesses, opportunities, risks and losses of any alternatives. Initial consideration of the most environmentally beneficial option is needed at each stage and iteration of the adaptive management cycle. This report does not cover projects where the initial options appraisal (during the drivers of change phase) recommends no intervention, working with natural processes or where entirely hard engineering options are the most suitable. It is instead used to identify where it is possible to use an IGGI solution instead of or alongside a grey engineering option.

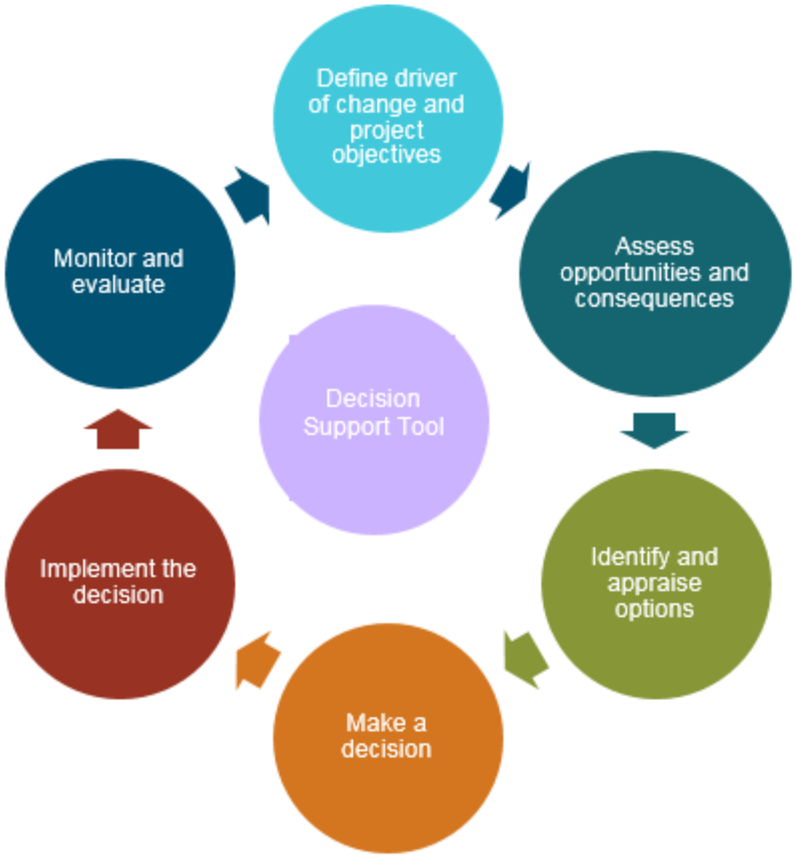


Figure 3.1 General decision-making process

Figure 3.2 Continuum of scheme scale decisions from no intervention through to a grey engineering solution, commonly used in flood risk management (after Roca et al., 2017).

3.3.2 DEFINE DRIVERS OF CHANGE AND PROJECT OBJECTIVES

In any project, it is important to define the key objectives explicitly; however, with IGGI projects this can add a layer of uncertainty as objectives can often be less familiar or more challenging to measure against expected outcomes. Improving biodiversity, habitat value and ecosystem 'enhancement' are complex and often subjective issues. Prioritising and quantifying what is possible, preferred, essential or sufficient, and issues of scale and timeframes can also be hugely important, often affecting the success of IGGI measures. Where an IGGI measure is part of a project that requires mitigation then these parameters will be more clearly defined; where the scheme is a general attempt to improve the environmental appeal or ecological value of an area, then the judgement of experts will be required to help determine what the key goals for habitat(s), assemblages and species are. The Critical Success Factors framework outlined in Chapter 4 enables practitioners to make more informed judgements on the relative value of IGGI approaches compared with traditional grey engineering options.

3.3.3 ASSESS STRATEGIC OPPORTUNITIES AND CONSEQUENCES

Before any option or a number of options have been identified, it is important to determine to what extent any potential benefits and consequences can be managed. Lawton's principles (Defra, 2010), and similar guidance at the landscape scale illustrate the need to look strategically when installing infrastructure, i.e. can any additional enhancements be created within the design? For example, can links be made to neighbouring habitats, can green networks be enhanced or barriers removed, allowing improved access? Can local groups be involved and to what extent can additional internal or third party funding be employed? If habitat is being removed, can it be offset elsewhere, of equal or additional value? Asset managers may have opportunities to combine multiple IGGI intervention types, across a single site, a linear asset, a network or at the landscape scale as part of strategic planning initiatives.

3.3.4 IDENTIFY AND APPRAISE POSSIBLE OPTIONS

The topic bundles (coastal, historic, mowing and urban) presented in Appendices 1- 4 are designed to help support practitioners in identifying possible IGGI measures and solutions that could be adopted or adapted for their particular schemes. Each case study includes a table expressing data quality based on its sources and quantity. This data quality table can be used to assess scheme specific, expert judgement and wider supporting evidence that underpins the data quality reported, helping assess the rigour of each case studies (see Chapter 4).

It is worth noting that many of these innovations have only been applied to particular contexts to date, but can potentially be applied much more widely in the future. For example, Vertipools (Case study CS-C5, Appendix 4) are pocket rock pools designed to be applied to vertical sea defences to create water retentive habitat features. These can be manufactured in an almost endless number of shapes and sizes, incorporate a range of textures inside and out, and can be placed at a variety of sites at the coast, at different heights within the tidal frame.

As many IGGI options are innovative and often location specific, the merits of scheme specific designs compared to business-as-usual options may need to be assessed. The Critical Success Factors framework (Chapter 4) was created as a tool to help appraise possible IGGI measures and solutions (Naylor et al. 2017). It has been designed and tested using the case studies presented in Appendices 1- 4 and can be used to evaluate other IGGI measures against a business-as-usual grey solution.

Issues of scale are key to the anticipated returns of many of the IGGI elements included here, and while this may be heavily influenced or solely determined by the budget of an individual scheme, it is important to establish how well IGGI is able to meet the aims of the scheme or help a scheme meet regulatory requirements or aid policy implementation. The case studies in each Bundle and the policies that can support IGGI implementation in section 1.2 can aid practitioners in identifying the most suitable IGGI measures and solutions for their scheme.

3.3.5 MAKE AND IMPLEMENT DECISION

As in any scheme, a decision will be made based on cost benefits, levels of risk and ability to provide returns for specific goals or achieve results under any particular drivers. The Critical Success Factors framework (Chapter 4) and the topic bundles (Appendices 1-4) presented in this report are designed to help demonstrate the cost benefits and risks to allow more informed decision-making when considering IGGI options.

Where the IGGI measure is part of installing a grey-engineered project then it is important to determine to what extent including it alters the installations process, for example, is it seasonal? Is it dependent on additional expertise or suppliers? Can the process begin immediately or are there preliminary works to be carried out?

3.3.6 MONITOR AND EVALUATE

Where green elements are installed, such as a freestanding green screen (Figure 2.4), it is important to monitor how well they establish after construction to measure their success in meeting policy or scheme targets. This can also boost the evidence of how well IGGI measures work in a range of settings. Often the long-term efficacy of ecological enhancement schemes is poorly monitored, even where it is part of mitigation for a development. Exceptions are those schemes where the IGGI innovation becomes part of third party research work, such as through collaboration with Universities.

4. INTRODUCTION TO THE CRTICAL SUCCESS FACTORS

Once a decision has been made to undertake a project, and the type and general design features are agreed, there are a number of scheme specific factors (e.g. cost, engineering, policy, ecosystem services etc.) that can be considered. These are the **Critical Success Factors** (CSF) and although they may not all apply to every scheme, they provide a framework to compare alternatives and establish useful metrics, which is essential for setting goals and determining if a scheme can be judged a success. The Critical Success Factors comprise a range of drivers, motivators, constraints, opportunities, costs and benefits that can be compared to business-as-usual.

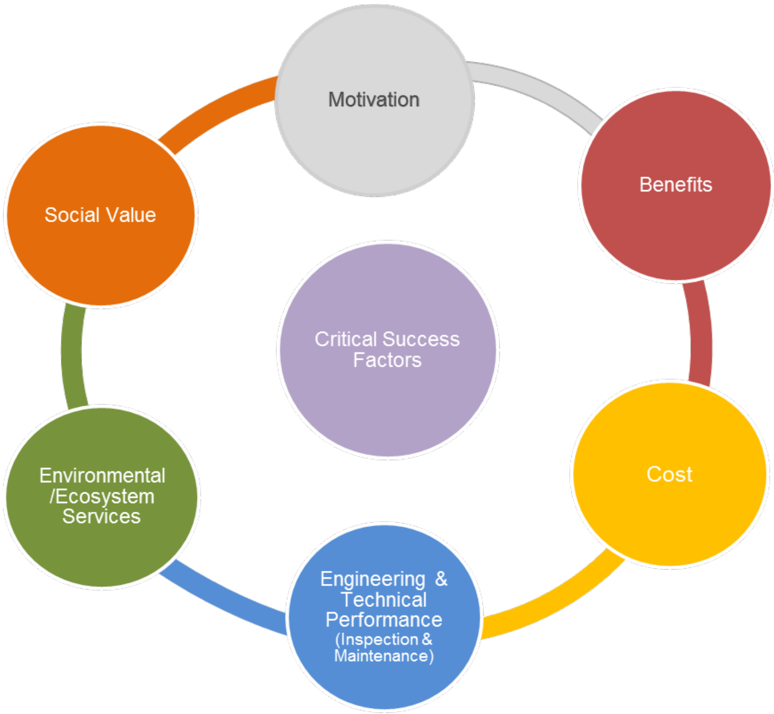


Figure 4.1. Critical Success Factors underpinning the decision support framework.

The CSF framework is designed to consider the range of policy, engineering, ecological and social parameters that have been, or could be, used to support, measure and/or improve the green credentials provided by greening hard infrastructure. The framework was developed through an iterative, co-production approach (Reyers et al. 2015) with the project partners (and HR Wallingford's work (Roca et al. 2017) on riverine green and green-grey infrastructure). The framework includes both engineering and ecosystem services elements identified through a series of meetings, teleconferences and workshops with project partners (Naylor et al. 2017). This aims to ensure the outputs are of direct value to engineers, environmental practitioners and a wide variety of users.

Aimed at building on the Benefits of Sustainable Drainage Tool (BeST) from CIRIA, the Construction Industry Research and Information Association (BeST, CIRIA, 2015), the CSF framework assesses the wider multifunctional benefits that IGGI can provide. The framework is designed to support existing ecosystem services documents and appraisal guidance documents, such as the Flood and Coastal Erosion Risk Management Appraisal Guidance (Environment Agency, 2010).

4.1 USING THE CRITICAL SUCCESS FACTORS

This section explains how the different IGGI measures presented in the bundles have been evaluated. In each case the same set of Critical Success Factors (CSF) are considered, as outlined in Table 4.1. Wherever possible, this has been done relative to a 'business-as-usual' (i.e. 'grey') baseline. This approach can help overcome barriers that may limit the uptake of these measures elsewhere. The information provided can help make a more reasoned assessment of the suitability of IGGI measures and provide mechanisms to support the approval process.

The CSF approach can help evaluate the benefits of adopting an IGGI measure compared to a grey engineering solution; this will be the case where the options appraisal has determined that alternative 'soft' solutions (e.g. Working with Natural Processes) are not suitable.

Table 4.1 Critical Success Factors - what are they?

Critical Success Factors	Description
Motivation	The strength of motivation (e.g. policy, biodiversity, reputation etc.) that led to an IGGI measure being adopted.
Benefits	The overall reason/positive outcome of including the IGGI measure.
Cost	Monetary costs associated with including an IGGI measure (relative to business-as-usual).
Engineering performance maintenance and inspection	Assessment of how/to what extent the IGGI measure influences asset function, maintenance and inspection. This includes an evaluation of whether the IGGI element has negative, neutral or positive effects on asset resilience.
Ecosystem Services (ES)	Evaluation of the environmental (primarily ecological) gains of a measure, and the evidence supporting this.
Social Value	Specific assessment of both tangible and intangible benefits to people and communities.
Case Study Criteria	Case studies were required to be data-rich against more than one critical success factor and operationally applied. Those carried out as part of research trials, or where only one CSF was measured in detail were included as art of the possible rather than case studies.
Data Quality	Assessment of the quality/robustness of economic, technical and environmental data available. This was a key determinant to distinguish between case studies and art of the possible.

The CSF framework was developed through an iterative process in close collaboration with the project partners. Potential case studies evaluated using each CSF were solicited from national agencies and were filtered based on the evidence available; good data on costs (that could be compared to business-as-usual) and ecological impacts (that could be compared with suitable control sites) were the primary selection criteria for case studies. In cases where such data were not available or limited, and therefore the CSF framework could not be fully applied, 'Art of the Possible' (AP) examples were instead used to showcase innovation. Where site-specific data were lacking, supporting information was gathered using expert judgement or wider evidence consistent with the EA appraisal tools (Environment Agency, 2016).

Each CSF is outlined in the following sections, including an indication of how they can be evaluated for planned works, allowing readers of this report to apply the CSF framework to their own schemes:

4.1.1 BENEFIT

This is the overall benefit of the scheme. This will either be a summation of the assessments for each critical success factor (in Figure 4.1 and outlined below) or a key benefit that significantly increases the viability of an IGGI measure, e.g. to meet a policy requirement. A visual representation of the cumulative benefits is given for each case study in the bundles at the end of this report using a 'benefits wheel'. This is designed to show the relative benefits/strengths of each CSF succinctly in a single diagram. This can help quickly identify what the key drivers and benefits were for each case study.

4.1.2 COSTS

Economic cost comparisons are crucial in making a strong business case. All costs should be calculated using the best available data (advice on this is available from the Green Book (HM Treasury 2003, 2011 update). Where specific costs are not available, assumptions may be made based on similar scheme/measure costs. In the bundles at the end of this report, a range of measures are presented which have been implemented across the last 5 years. Costs have therefore not been standardised across years. However, to maximise comparability, costs in the case studies were calculated as 'per meter' where applicable and where applicable, made use of standardised costs for specific infrastructure types such as coastal and estuarine flood alleviation (EA, 2010).

Adopting an IGGI measure may simply involve an additional cost on top of the business-as-usual price (e.g. 'an additional £100 per metre of defence'). In other cases, including an IGGI measure in a scheme may require changes to the design of a particular element, materials and equipment used in construction, and/or the maintenance regime of an asset. These additional costs should be included in assessments using existing examples and published documents wherever possible. Guidance may be sought from relevant experts and/or standard industry reference materials such as the Environment Agency (EA) flood risk management estimating guide/cost unit database (Environment Agency, 2010).

For each measure being evaluated, cost elements can be assessed as:

1. **Net cost –** where data permitted this was the per unit (e.g. cost per linear metre) cost of the IGGI measure. Often these data were not available or difficult to disentangle from the total project costs, in these instances the cost of the entire project is reported for as much as the design life that data were available.

2. **Direct (construction) cost –** the estimated or known capital expenditure (capex) cost of construction including the proposed IGGI measure in a scheme and/or adopting it instead of a grey measure. This can be estimated at the business case stage using case studies, standard industry information (possibly from contractors, suppliers and installers). This may consider things like additional 3rd party funding availability, insurances and research, requirements for environmental assessments, etc. Where possible the IGGI component of the construction costs were separated from the overall construction costs.
3. **Cost compared to business-as-usual –** the cost of undertaking the innovation/IGGI measure relative to that of standard practice/ grey solutions. This can be based on existing data on project costs (e.g. EA/DEFRA cost estimates for fluvial and coastal protection works (EA 2015a; 2015b)), estimates and actual figures based on completed projects, cumulative costs of individual elements, and expert judgement. Comparison with business-as-usual is needed in order to determine a cost–benefit value for the IGGI measure. It is especially useful for making a business case where additional benefits assessed elsewhere in the CSF framework are considered greater than any additional costs. This cost can be effective for identifying 'quick wins' where an IGGI measure represents a savings on the business-as-usual *and* provides wider benefits.
4. **Long-term cost –** an estimate of overall financial impact across design-life of the project (often referred to as Totex – a term used to represent the total or whole life costs of infrastructure) and/or the anticipated future maintenance costs where whole life (or Totex) costs were not available. This includes any self-sustaining elements and what any required long-term maintenance of the measure might cost in various scenarios including consideration of climate change. These impacts on costs can be negative (e.g. an IGGI element having a shorter design life and therefore requiring repair/replacement sooner compared to business-as-usual) or positive (e.g. increased asset resilience to on-going decay afforded by the greened element).

4.1.3 ENGINEERING PERFORMANCE, INSPECTION AND MAINTENANCE

Limited information about how the engineering performance (the primary requirement for any scheme) and maintenance needs of an asset might be changed by incorporating greening measures is a major barrier for wider uptake. Addressing these uncertainties is crucial for assuring engineers, funders and other stakeholders that the project can be successful. Much of this assessment will involve expert judgement and/or information from similar schemes. Using case studies (such as those included in the bundles in Appendices 1-4 of this report) can be extremely helpful in overcoming some of these uncertainties. Key aspects to consider are:

Performance

Incorporating GI into grey infrastructure can improve or limit engineering performance, asset resilience and design life across short, medium and long timescales. It is important that this is understood and well communicated from the outset to manage expectations, maintain buy-in and to ensure that risks or unknowns are clear and understood during the options appraisal phase of a project. IGGI measures will influence grey infrastructure to varying degrees, from having a negative impact on long-term performance (they may not last as long as grey solutions) to having a neutral influence (no effect on performance) to a positive impact (by increasing asset resilience). Where the IGGI measure can have a significant influence on engineering performance this should be reflected in planning how and where it should be implemented, e.g. seeking additional expert judgement, determining more detailed site-specific prediction and modelling, or reducing risk by applying the measure in low risk environments, or incrementally.

Inspection

Extensive vegetation cover and/or presence of protected species can make visual inspection of grey assets more challenging (e.g. plants covering walls). In some cases this may easily be mitigated against, but it is worth considering any necessary changes to inspection regimes. In some instances the IGGI measure may aid inspection. For example, where vegetated terraces accrete material and develop salt marsh habitat at the toe of block wall sea defences, then signs of marsh erosion may be indicative of deterioration of the wall.

Maintenance

Projects that include working with natural processes tend to benefit from the self-regenerative capacity of plants, but this can still involve maintenance work such as maintaining ecosystems and/or removing undesirable species. These positive and negative elements need to be factored in to any business plan.

Asset Resilience

The effects of the IGGI measure on the resilience of the assets they are built within, inhabit or grow in front of was assessed using data (where available such as in the Historic and Coastal bundles) or via expert judgement. This was used to evaluate whether the effect of the IGGI measure was negative, neutral or positive on the resilience of the asset to deteriorative agents. No IGGI measures were found to negatively influence asset resilience, many were neutral and some had positive effects on asset resilience.

4.1.4 ECOSYSTEM SERVICES

Most IGGI measures are environmental enhancements; they can provide habitat where there was little or none and can support individual species or wider biodiversity. They are not designed to restore or recreate natural habitats completely but instead to improve the ecological function of grey infrastructure.

To evaluate these ecological services, it is useful to consider whether ecological goals form part of the motivation for adopting a particular IGGI measure. To evaluate success, comparisons can be made against these original aims, business-as-usual options and/or experimental ‘control’ sites within the same scheme, nearby or at other locations with comparable environmental conditions. In the case studies included in the bundles, the most useful data were derived from ecological monitoring after asset construction – ideally in comparison to a baseline collected before construction began. Simple ecological metrics (e.g. number of species, number of target individuals etc.) can provide useful evidence on environmental performance. In the majority of cases these data were used to provide qualitative assessments of the ecosystem services value provided by the habitat created. Limited data on provisioning services or on the tangible benefits of increased regulating services such as air pollutant trapping meant that quantitative metrics were limited. More robust data across multiple ecosystem services is required to fully evaluate and quantify the ecosystem service benefits in future. This would allow a more realistic comparison of the financial benefits of IGGI measures compared to business as usual grey engineering.

4.1.5 SOCIAL VALUE

As well as ecological services, IGGI measures can have benefits for people that should be included in a business case. Some of these benefits can be long-term and relatively low cost, particularly when assessed against chronic and intractable socio-economic and health issues. This is increasingly reflected in wider policy and guidance (see Section 1.2). Clearly defined aims, metrics and monitoring regimes should be established at an early stage, as helping to deliver benefits for local communities can provide valuable impetus for choosing an IGGI option. This can include meeting regulatory requirements, e.g. planning. As well as any site-specific information, tools may be available to help evaluate social value, including Building Information Management system files, greenspace maps, social and health data and similar databases.

In addition to improving the wellbeing of 'users', the externalities from including GI in developments can include increased commerciality, improved aesthetics, raising the desirability of an area (e.g. higher rental returns and property prices), reduced employers staff sickness costs and improved staff retention rates. Greening can also offer corporate social responsibility opportunities and chances for businesses to improve public relations.

Social data are often difficult to obtain. In the case studies in the bundles, expert judgement has been used, often involving qualitative inferences from other geographically or economically similar schemes.

4.2 DATA QUALITY

An important issue when building a business case is the existing evidence base, as this can provide important leverage in getting new greening measures approved. To help with this, 'data quality' has been assessed and shown in a simple table at the end of each case study. In each instance, the type of data (economic, engineering and environmental) is evaluated using a combination of expert judgement, availability of scheme-specific information and wider supporting evidence.

For example, the highest quality data would represent a measure that has been tested/implemented in multiple locations, where pre- and post-installation monitoring data are available, where multiple supporting sources are available from other similar projects, and where several experts agree on its relative benefits/impacts.

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7. BUNDLES

The design and contents of each bundle were developed iteratively in close coordination with project partners, advisors and/or contributors. Specific design features were agreed to ensure that the contents of the bundle were useful for readers from a diverse range of backgrounds (e.g. engineers, project managers, ecologists and policy makers). Icons and a colour scheme were developed to ensure quick, clear and simple access to the contents of the bundles. The materials, along with this report, were reviewed and for the coastal bundles, an independent engineering expert judgement review was also undertaken to assess the risks of IGGI to engineering performance. The limitations, risks and opportunities associated with each topic are presented in the business case in each bundle.

7.1 CASE STUDIES

Several case studies are included for each of the coastal, historic, urban and mowing bundles. These case studies are examples of IGGI measures for which the best data were available. In each case, the assessment of key Critical Success Factors are summarised in a diagram (at the start of the case study), as explained in Table 6.1. Case studies provide an overview of the measure (e.g. what it involves, how it works and the motivation for its use) and outlines its assessment against each of the Critical Success Factors (benefits, cost, engineering performance inspection and maintenance, ecosystem services and social value).

Table 6.1 'Sliders' showing overall values of key parameters

Parameter	Score		
	Negative	Neutral	Positive
Benefit	Increase in cost relative to other benefits/Critical Success Factors	No change	Overall improvement against Critical Success Factors
Ecosystem services (ES)	Overall reduction in habitat quality / ecosystem service provision	No change	Increased ecosystem service provision/ Measureable improvement in environment
Engineering, performance, inspection, maintenance and asset resilience	Increased need, cost and/or complexity or reduced design life	Neutral / No impact	Improved asset resilience or reduced need, cost or complexity of maintenance
Cost (capital or whole life where possible)	Overall increase in cost	No change	Benefits outweigh any increase in cost

In addition to the CSF, the possible application of each measure in other locations/on other grey assets is broadly evaluated. This is done by considering which organisations/asset owners and asset types the case study might also be applicable. Similarly, opportunities for 'scaling up the benefits' of the case studies are evaluated, often involving simple but informative extrapolation of costs and ecosystem services.

The quality of the supporting data is assessed in a simple table at the end of each case study (see Chapter 4). Sources and contacts for further specific information about each case study are also provided.

7.2 ART OF THE POSSIBLE

These provide shorter examples of innovative research ideas that have not yet been tested operationally, are at the early stages of development and/or are lacking control sites to compare against. In many cases, they have a very high quality of data (e.g. biodiversity value), but only this Critical Success Factor was measured rather than having data for a range of metrics. As such, these examples require more supporting data for further evaluation to be able to compare with business-as-usual ('grey') options. Although these examples are less data rich than the full case studies, they demonstrate a range of ideas for enhancing hard infrastructure. They often represent a 'proof of concept', showing that a broader range of habitat enhancements and associated benefits are possible than those covered by the case studies.

APPENDICES - BUNDLES

All of the outputs for each environment topic covered in this report have been bundled by topic (Historic, Urban, Mowing, Coastal). These are contained in Appendices 1-4 and are available to download as an entire project report (this report + all four appendices) or as individual units (Appendices 1-4). Together the content of the bundles can be used to extend the range of urban greening beyond that which is covered as part of most GI policies (Figure 7.1A-B).

APPENDIX 1 - HISTORIC

APPENDIX 2 - URBAN

APPENDIX 3 - MOWING

APPENDIX 4 - COASTAL

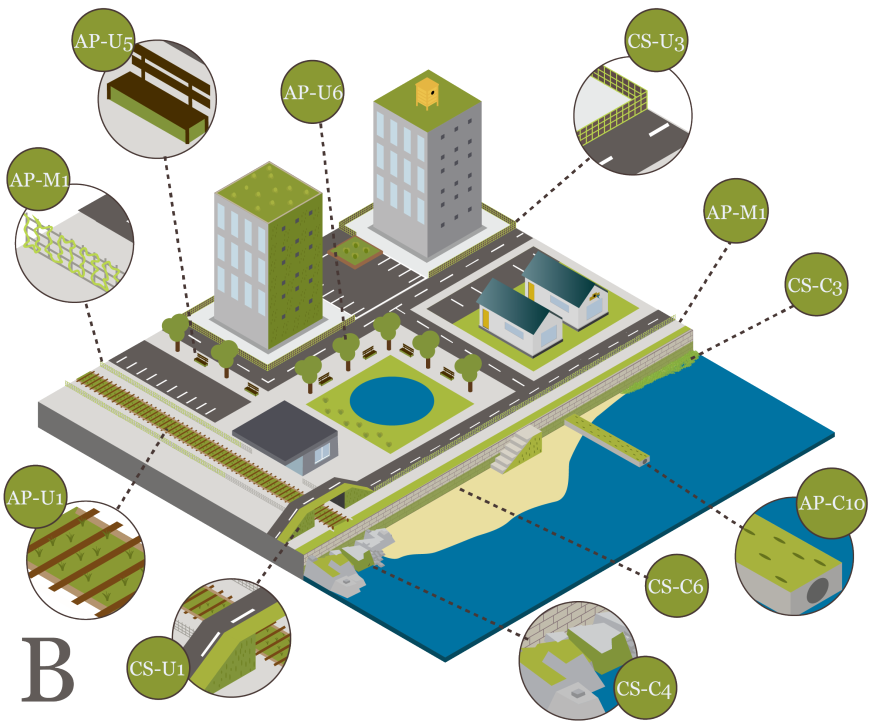


Figure 7.1 A-B. A: Urban greening that is part of GI policy. B: Illustrating the benefits of adding IGGI to the range of urban GI measures used where each label refers to a specific example found within the topic bundles in Appendices 1-4.

Appendices:
Innovations in Integrated Grey-Green Infrastructure that can be used to green the greyest parts of our cities and towns.

These appendices provide case studies and art of the possible examples for four environment topics covered in this project.

Historic
Urban
Mowing
Coastal

These appendices cover the four environment topics contained within the NERC funded project report:
Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Appendix 1: Historic

This appendix is one of four environment topics covered as part of the NERC funded project report: Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Business Case: Historical Innovations


image ©Historic Environment Scotland

This business case assesses the existing evidence of integrated green grey infrastructure (IGGI) measures that can support wider implementation on historic buildings, ruins and sites. It forms part of the NERC funded IGGIframe project outputs (URL: http://eprints.gla.ac.uk/150672/). Costs, benefits and measures of the engineering and ecological performance (called critical success factors) of a range of IGGI alternatives to traditional 'grey' approaches are drawn from operational and research examples across the UK and beyond.

Measures considered involve adding soil and/or vegetation to the tops (CS-H1; AP-H1; AP-H2) and the faces (AP-H3; AP-H4) and reburial of ruins (CS-H2). The business case is aimed at reducing the uncertainties when considering GI innovations, including:

- What are they?
- Where have they been applied?
- What evidence is there to show they work?
- Costs
- What are the benefits over business as usual?
- What measures and solutions are there?
- Where are they suitable?
- What are the risks?
- How can I get approval?
- What are the wider corporate benefits?

What are they?

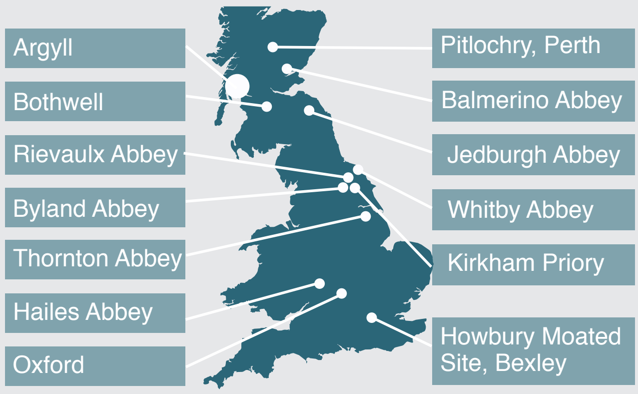
Innovative adaptations to traditional management of historic assets in historic conservation areas including ruined sites and free-standing walls. Most measures involve using nature-based approaches to limit/slow on-going deterioration of historic conservation assets (e.g. soft capping of walls) or alternative management strategies to minimise deterioration (e.g. reburial). Some measures also offer opportunities to support or increase local biodiversity.

When in the design/life of an asset can this be applied?

Methods aimed at slowing deterioration/aiding conservation of existing historic assets may be applied at any point, but may be most cost effective when the current risk of damage/deterioration is high. The measures described here can be used in other historic conservation settings around the UK, and with further study, could be adapted for use on the modern built environment.

For new build schemes within historic areas, possible green measures such as those in the urban, mowing and coastal bundles should be considered as part of strategic or design stages as well as retrospectively or as part of on-going maintenance.

Where has this innovation been tested or applied?



Evidence Summary

The evidence summary and benefits assessment are a summary of the critical success factors evaluated for all of the coastal case studies and 'Art of the Possible' examples. It is replicated across the four business cases to enable comparison between environmental contexts.

Costs

What do they cost compared to business-as-usual?

Often less expensive to install compared to traditional grey solutions. Generally less expensive in the long-run, sometimes requiring less maintenance and repair.

LESS OR THE SAME

Ecosystem Services

What evidence do we have that they deliver ecosystem service benefits?

The primary driver for heritage assets is typically improving resilience. However, in many cases greening approaches bring additional environmental benefits including local biodiversity gains.

POSITIVE

Engineering

Are there any risks to design life, inspection or effects on maintenance regimes?

Most of the measures are developed to increase design life by improving asset resilience. Altered or new maintenance regimes are required, although this is often less or similar to business as usual in terms of costs and personnel time.

POSITIVE

Policy

How does it relate to policy and guidance?

Measures can contribute to wider policy aims and national guidance for historic sites and assets including on-going physical conservation, and reinforcing and enhancing access and presentation of sites for the general public.

ACHIEVED

Social

What are the potential additional social benefits?

The wider benefits beyond cultural ecosystem services have not been assessed, although there may be some aesthetic and educational benefits of GI approaches.

UNKNOWN

Reputation

How have the schemes helped improve public perceptions?

Greening of historical assets is divisive, but there is evidence that the public are generally in favour where this is shown to help conservation.

NEUTRAL

Asset Resilience

How have the schemes and measures influenced asset resilience to on-going deterioration?

Some measures can significantly help manage/limit damage to valued historic assets caused by weathering-related deterioration.

POSITIVE

Data Quality

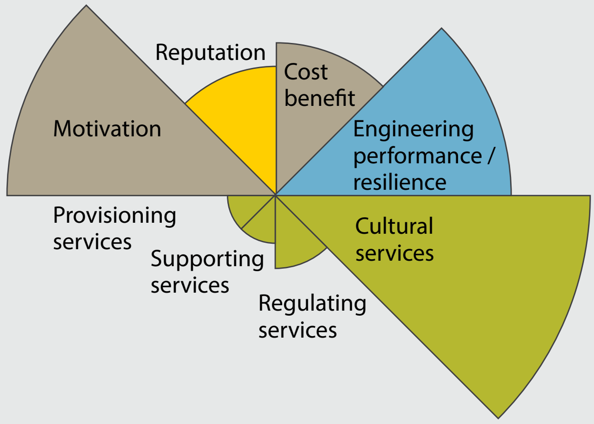
What is the evidence base for IGGI approaches in the historic environment?

Site specific ecological data for each example was typically high, other data types varied.

MODERATE - HIGH

Benefits Assessment

The evidence summary presented above is derived from the examples contained in this bundle, each of which have been assessed using the **Critical Success Factors** guidance. The benefits wheels show the benefits of each critical success factor relative to each other. They are a combination of ecosystem services and other important engineering and social considerations necessary to evaluate IGGI measures compared to business as usual. More detailed breakdown of each element can be found below.



Cost
These approaches can provide value for money as a long-term approach to maintenance and conservation. They can contribute to conservation of historic assets with, often, low to moderate installation and maintenance costs, and can maintain opportunities for subsequent research of the asset/site that can help reveal and support heritage values for the general public.

Engineering value
Some approaches have been developed primarily to improve asset resilience (against on-going deterioration) and maintain the long-term cultural value of historic structures, including already ruined sites. The success of these approaches is shown by their increasing application by statutory authorities such as Historic England and Historic Environment Scotland.

Cultural services
Measures that contribute to the on-going conservation of historic assets and sites can help sustain cultural heritage values. This includes the physical protection of materials and structures themselves, but also improving site aesthetics, education and experience for visitors.

Regulating services
There is limited study and evidence of regulating services (for people) from IGGI approaches in historic settings. However, greening measures can support improved air quality at a local scale.

Provisioning services
Likely to be very limited due to the scale and nature of these enhancements.

Supporting services
Introduction of soil and vegetation to historic sites and assets can support local biodiversity, including some rare species. Managing vegetation for primarily heritage conservation reasons can offer opportunities to improve conditions for insects and birds (e.g. ivy growing on historic assets where appropriate). Further evidence is needed.

Motivation
Motivation for the options outlined here is primarily the long-term conservation of historic assets as a heritage resource. This is especially for the case for vulnerable assets that are already at threat from on-going deterioration caused by environmental impacts such as weathering. Existing ('grey') approaches to conservation (e.g. hard capping) may also be inappropriate or ineffective and costly in some cases, with a need to develop and trial new greener and more sustainable solutions.

Policy
Experimental work on historic assets and at test sites are informing practice in the heritage sector, particularly those that have a very strong evidence base such as soft capping. Major guidance documents have been recently produced that outline this evidence, providing practical information for heritage asset managers/owners aiming to adopt some of these measures (see individual Case Studies and Art of the Possible examples for relevant references).

Reputation
Opinion on 'greening' of historic sites and assets is not clear cut. When coupled with adequate education and engagement, the public are often very positive about introducing nature into the historic environment. On the other hand, barriers do exist due to the potential for biodeterioration and issues of perceived neglect/mismanagement of valuable heritage.

IGGI Measures

The IGGI measures in this bundle are mostly local/site based trials carried out as part of scientific research studies. This includes some work using purpose-built test structures that are more appropriate for testing and developing techniques than using existing heritage assets. Some examples are based at the 'operational' scale, where greening (alongside other 'soft' measures such as reburial) of entire sites/ruins has been undertaken to support wider efforts to conserve historic asset in the long-term.

Most of the measures outlined involve changes to the ways in which vegetation is managed, whether actively introducing it (e.g. soft capping) or altering approaches to its maintenance/removal (e.g. ivy on walls). These approaches aim to capitalise on the ability of vegetation of 'buffer' other factors that can contribute to on-going deterioration of vulnerable historic materials, including temperature and moisture cycles, and frost damage. Reburial of ruined sites and other archaeological remains is also primarily aimed at stabilising environmental conditions to limit further deterioration.

What types of infrastructure?

These measures have been tested or applied to a range of historic assets including freestanding and retaining walls and ruins. We have grouped these into three broad types:
(1) wall face
(2) wall tops
(3) ruins.

Case Studies

Type	Aim of the IGGI	Label	Title
Wall top	Soft capping of historic free-standing walls to improve asset resilience	CS-H1	Soft capping of historic walls, England
Ruin	Reburial of historic ruins to better conserve them	CS-H2	Reburial of historic ruins, Scotland

Art of the Possible

Type	Aim of the IGGI	Label	Title
Wall top	Soft capping of historic free-standing walls to improve asset resilience	AP-H1	Soft capping of historic walls
Wall top	Understanding and managing ivy on walls to reduce deterioration	AP-H2	Ivy on historic walls: bioprotection
Wall face	Understanding and managing ivy on walls to reduce deterioration	AP-H3	Ivy on historic walls: bioprotection
Wall face	Managing ivy on walls to attenuate pollutants and improve asset resilience	AP-H4	Ivy on historic walls: pollution biofilter

Two measures in the coastal bundle have also been applied in historic conservation areas or on historic conservation assets. These include ecological enhancement of a coastal flood alleviation scheme in Shaldon, Devon (CS-C7) and test panels of textured concrete for marine biodiversity (AP-C8) tested on the historic pier at Blackness Castle, Scotland. Other coastal IGGI measures shown to encourage faster colonisation by intertidal species (e.g. AP-C7) may also be applied to historic coastal assets to make repairs blend in more swiftly to improve amenity and habitat provision.

IGGI Solutions

IGGI measures on historic assets and in historic conservation areas can contribute to wider greening approaches to environmental enhancement. Measures are typically very local scale, but can provide elements of 'green' that improve habitat connectivity. In combination with measures in urban and coastal environments, greening of historic assets can form a valuable part of landscape-scale IGGI solutions.


image ©Historic England

What ecological factors need to be considered?

It is important to consider the ecological suitability of the IGGI measures for a given location and for different types of historical assets and their component materials. Timing of application, the kinds of species used and maintenance practices can influence the likely success of greening measures and their ability to support beneficial biodiversity. Similarly, given that the measures described in the bundle are primarily intended to aid conservation of the assets, biodiversity gains are only a secondary aim and may be generally limited, but can be locally significant. Further details of these kinds of considerations are provided on the risks page of this business case.


image ©Historic Environment Scotland


image ©Historic Environment Scotland

How can you get this type of greening approved for your scheme?

The case studies, art of the possible examples and policy links provided here can be used to demonstrate the economic, environmental and social benefits that can be gained from adding IGGI measures to historic conservation projects. They also provide clear evidence of the policies that have been used as statutory climate change (AP-H1) or environmental impact assessment (CS-C7) or non-statutory, organisational strategy (CS-H1, CS-H2) drivers.

Where no statutory mitigation is required, how else can you get this type of greening approved? Many of the examples only require a willingness to innovate, as testing or applying IGGI measures often requires minimal change in behaviour or practice. Some examples illustrate how changes in operational practice (e.g. CS-H1, AP-H1 to AP-H3) can support on-going conservation of culturally valued assets or sites at reduced cost compared to business as usual, and provide some additional local benefits such as increased habitat provision for wildlife and improved asset resilience through pollutant trapping (AP-H4).

Known limitations or risks associated with these IGGI approaches

There is increasing evidence of the value of some greening approaches for helping to conserve vulnerable historic assets and sites, including experimental research at a number of different sites across the UK. There are important limitations that need to be considered however, especially as the assets involved are often valued as national heritage, and recognising that greening will not be appropriate in all cases. Risks associated with the measures described in the bundle include:

Risk Factor	Description and Risk Reduction Strategies
Establishment of soft caps	Establishment of plants can be weather dependant and watering may be required during dry or warm periods post-construction. Birds may remove plug-plants from some soft capping sites.
Geography	Soft capping may not be suitable for very dry or drought-prone sites, or more drought tolerant species would be required.
Biodiversity	As a secondary aim to the conservation of the asset, there is limited data on the ecological benefits of soft capping and ivy on historic assets; further study would be beneficial. However, vertical vegetation, including ivy, is known to be very beneficial for wildlife.
Maintenance	Routine maintenance is needed to remove any woody vegetation from soft caps and to undertake some repair/replacement of damaged areas of capping that may occur over time. Ivy must be monitored and kept away from guttering and roofs, with annual trimming recommended.
Aesthetics	Soft capping of walls may initially look 'unusual' until established, when they appear more naturalistic. Vertical vegetation like ivy is not appropriate where it obscures valued features such as architectural detailing. Vegetation on historic assets can be seen as 'neglectful' by members of the public.

Where to learn more

Coombes, MA, Viles, HA, Cathersides, A. (Forthcoming) Ivy on Walls. Historic England Research Reports Series.

Hanssen, SV, Viles, H. (2014) Can plants keep ruins dry? A quantitative assessment of the effect of soft capping on rainwater flows over ruined walls. Ecological Engineering, 73: 173-179.

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Morton, T. et. al. (2011). Soft capping in Scotland: the content and potential of using plants to protect masonry, Historic Scotland Research Report. URL: https://www.engineshed.org/publications/publication/?publicationId=5a2c8f33-dc6a-4604-9df6-a5af00960d7b

Scottish Government. (2014) Our place in time - The Historic Environment Strategy for Scotland. URL: http://www.gov.scot/Resource/0044/00445046.pdf

Sternberg, T, Viles, H, Cathersides, A, Edwards, M. (2010). Dust particulate absorption by ivy (*Hedera helix L*) on historic walls in urban environments.

How to cite: Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Historic Case Studies

Case Study CS-H1:

Soft Capping - Historic England

Summary

Placing soil and grass on the tops of ruined walls to aid conservation offers a viable alternative to traditional hard capping. Eight years of experiments, field trials and monitoring by Historic England and the University of Oxford at multiple historic sites demonstrate how this approach can not only reduce rates of deterioration, but also support biodiversity and reduce costs. Based on this evidence, all of the ruins at Hailes Abbey, Gloucestershire, were soft capped in 2013 and this is proving very successful.

Benefit	MEDIUM
Engineering	MEDIUM
Ecosystem	LOW
Cost	LOW

How does it work?

Ruined and free-standing walls are exposed to rain, thermal fluctuations and frost that cause deterioration over time. Hard caps of stone and mortar have traditionally been used to consolidate wall tops and minimise on-going damage, but these often crack/ deteriorate quickly requiring regular maintenance and repair. Using soil and vegetation to cap walls offers an alternative, and there is strong evidence that such soft caps are effective at buffering fluctuations in temperature (including frost) and moisture, and thereby protect the tops of walls from further damage. Soft caps also reduce the amount of rainwater running down the face of walls that can increase the harmful weathering of face stones and cause unsightly surface staining.

Motivation

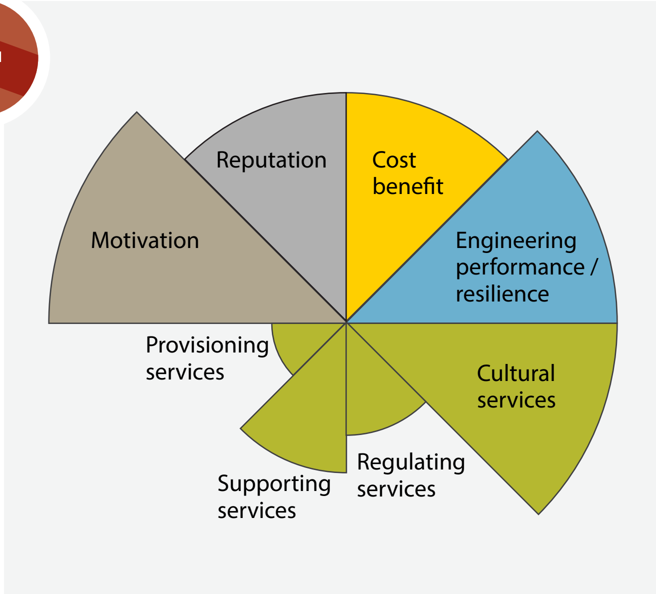
Hailes Abbey suffers from flooding and is situated in a frost hollow and many of the walls were in very poor condition and deteriorating rapidly, requiring frequent and costly repairs to the hard capping in the past. Previous soft capping trials at the site had proved effective, supporting the decision to soft cap the entire monument as a more sustainable and cost-effective way of conserving the ruin.

Design Innovation / Enhancement measure

Hailes Abbey, a 13th Century Cistercian abbey, was the first Scheduled Ancient Monument in England to be entirely soft capped, in 2013. Soft caps were applied on all sections of exposed wall, including at ground level and walls up to 5 m in height. The cap consisted of locally-cut turf with a thickness of c. 10 cm. In some areas small sedum plants were added subsequently to help prevent edge erosion.

Benefits

Although costs can vary (see below) the soft capping method has proven to be a cost effective, low maintenance method of conservation that reduces costly maintenance and repair cycles for asset managers. It also provides a degree of ecological enhancement of value in itself; greening ruins provides some aesthetic appeal and limited regulating (e.g. water attenuation) and supporting (e.g. habitat provision) ecosystem services. Results of preliminary trials here and in Scotland (see AP-H1 and AP-H2) show it can be a useful asset management tool that can achieve desired engineering performance outcomes and provide ecosystem services.



Net Cost

Trial installations of soft capping at three sites (Byland Abbey, Kirkham Priory, Thornton Abbey) were fully costed based on 2005 prices for a research rather than commercial installation. Soft capping costs ranged from £39 to £75 per m^2 (using 10 cm thick soil and turf cut on site). The higher costs in the range largely reflect the need for scaffolding to install capping on higher walls.

Direct cost of intervention

Other costs include labour, materials and equipment (e.g., turf cutter hire). If installed carefully, maintenance costs are minimal.

Cost compared to business-as -usual

Hard capping costs at the same sites were calculated as £567 to £991 per m^2 at 2005 prices using suitable stone and lime mortar. These costs incorporate additional costs of a stonemason, materials, removal and recording of any existing consolidation, salvaging original stonework, and additional time to select and source appropriate replacement stone. Soft caps can be easily installed in a matter of days – hard capping (when done properly) may take considerably longer.

Per meter of wall, soft capping at three fully-costed sites at 2005 prices was around 13 to 15 times less expensive than using hard capping.

Long-term cost

Once a soft cap is established the maintenance costs should be minimal (see following section). Long-term cost savings will be positive given that walls are expected to deteriorate more slowly and require less frequent intervention/ repair. There is currently minimal evidence to indicate the likely scale of these savings over the long term.

Engineering performance, inspection and maintenance

Experimental evidence and site monitoring shows that soft capping will reduce fabric loss from walls by providing a thermal blanket on wall heads, which reduces deterioration caused by freezing events and repeated thermal expansion and contraction. At Hailes Abbey, trial soft capping also led to generally lower levels of moisture and reduced moisture fluctuations in the underlying walls compared to uncapped walls. Soft caps are also more effective at shedding water away from walls than hard caps, reducing the amount of water running down the wall face during heavy rain that can lead to decay and surface staining.

Research has been undertaken to address performance concerns relating to possible damaging effects of vegetation on stone walls. This has shown that a soft cap reduces the amount of water reaching the wall head, and that this water is not acidified and therefore does not enhance chemical degradation of the stonework. Furthermore, grass and sedum roots are not woody and pose little if any risk of enhanced deterioration. Occasionally, woody species may become established in soft caps, and these should be removed immediately once identified.

Installation of soft capping requires careful timing (ideally between October and February), as new caps are very prone to drying out. An initial period of regular watering (around 3 months) is advised to help the cap establish. Exposed edges can be especially prone to drying out and then eroded during heavy rain and this can lead to failure of the caps to establish if not monitored. This can be partially overcome by introducing more drought resilient plants, particularly sedums. These can be inserted as plugs to the edges of turf caps to improve stability.

Once established, soft caps are generally low maintenance and are considered largely self-maintaining, particularly in comparison to hard capping. Where/if growth becomes excessive a cap may benefit from being trimmed back. Assessment of the general condition of the cap, including evidence of edge erosion, should take place every 5 years. Woody species should be identified and removed on an annual/biennial basis.

Ecosystem services

Soft capping functions as additional habitat for plants, insects and birds that hard-capped walls do not provide. Plant communities forming soft caps are dynamic and change naturally over time, and may support locally similar but distinct species assemblages.

Ecological surveys of sections of turf capping originally installed at Hailes Abbey in 2005 were carried out in 2007 and 2011. A comparison was made in an adjacent field site where the turf was sourced. In 2007 the communities both in the field and on the wall were classified as MG6a *Lolium perenne-Cynosurus cristatus* grassland following National Vegetation Classification (NVC). Perennial rye-grass was less common within the soft-cap than the field, whereas Cocksfoot and Red fescue were more abundant. By 2011 considerable changes in the community had occurred, classified as MG11a (*Festuca rubra-Agrostis stolonifera-Potentilla anserine* grassland) Lolium perenne sub-community. The changes likely reflect progressive leaching of nutrients and lack of moisture on the soft cap.

By slowing the deterioration of valued historic assets soft capping provides a cultural service. Many people also place greater aesthetic value in 'natural looking' ruins, and using vegetation to slow deterioration may therefore support broader efforts to engage the public with historic sites (see social value).

Social value

A detailed visitor perception study at Hailes Abbey found that around 78% of visitors has a positive perception of the capping and 16% had a negative view (the remainder were neutral). Those with a negative view were more accepting once educated about the conservation benefits of a soft cap. Based on a choice of photographs, around half of visitors (47%) preferred the ruin after it had been soft capped, 12% preferred it with natural vegetation (based on a 1937 photograph) and 20% indicated preference for no vegetation. There was also a general interest from visitors for more on-site information about soft capping of the ruin, indicating educational opportunities.

Who can apply this intervention / technique?

Soft capping could be applied to any historic freestanding wall or ruin, with appropriate prior consultation but if the structure is listed or scheduled, consent will be needed. In situations where hard capping has been applied but is currently failing, or where unconsolidated walls are rapidly deteriorating, soft capping can be a viable option. Height and composition of walls do not appear to affect success, but thin walls (< 30 cm) may be less suitable to support a healthy soft cap. Drought-tolerant sedums are considered crucial for the success of soft caps on thinner walls. Walls with flat heads will be most suitable for soft capping, whereas rough wall heads may require additional soil to level out the surface.

Scaling up the benefits

Soft capping has been shown to perform well on walls made from a range of materials including limestone, sandstone, brick and flint. Equally, the moderating influence of soft capping has been consistent across a range of climatic settings in England, including Yorkshire, Gloucestershire, Oxfordshire, Norfolk and Greater London. Overall, soft capping is also considered a good interim conservation solution for ruined sites as it can be both installed and removed relatively quickly and easily.

Where left undisturbed and given enough time, walls often acquire a natural ‘soft cap’. There is little research on the possible benefits of these, but they are likely to function in a similar way to installed soft caps. Where conservation of historic fabric is not a key driver, soft capping may still be a viable option for greening of boundary, retaining and other types of free-standing walls, including in urban areas, to support wildlife and create new green space.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
COST			●	●			●
ENGINEERING			●	●			●
ECOSYSTEM			●	●		●	

Further information / Contacts

Historic England (Forthcoming) Soft Capping of Ruined Walls. Research Reports Series XXX-XXXX.

Prof. Heather Viles, University of Oxford:
Heather.viles@ouce.ox.ac.uk

Lee, Z, Viles, HA, Wood, CH. (editors). (2009). Soft capping historic walls: A better way of conserving ruins? English Heritage Research Project Report. URL: https://historicengland.org.uk/images-books/publications/soft-capping-historic-walls/

Chris Wood, Historic England:
Chris.wood@historicengland.org.uk

This forms part of Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Case Study CS-H2:

Reburial of historic monuments

Summary

Reburial of historic monuments at Jedburgh Abbey, Scottish Borders. An innovative scheme to rebury parts of the masonry at most risk. Vegetation and growing medium were applied to the top of the monuments. Monitoring and assessments of the impacts might prove useful for preserving many other buildings at risk in Scotland and elsewhere.

Benefit	MEDIUM
Engineering	IMPROVED
Ecosystem	LOW
Cost	MUCH LESS

How does it work?

Thirty years of wetting–drying and frost cycling had damaged the red sandstone masonry on the South Range of Jedburgh Abbey, a ruined Augustinian abbey in the Scottish Borders. Repairs and consolidation with cement-based mortar had exacerbated the damage of the clay rich sandstone. Removal and replacement of the mortar with a lime-based cement would have been damaging, and selective replacement of the most damaged stones would have reduced the detail and appeared incongruous. Reburial was deemed most preferable, least damaging option. In November 2015 the masonry was covered with an isolating layer of geotextile, and a protective (soft) capping of puddle clay tempered with sand was created, at least 100 mm thick, topped with two layers of turf.

Motivation

Exposed historic masonry is at risk from a number of factors including physical and chemical weathering from pollution and climate change. The site at Jedburgh presented opportunities to test innovative reburial techniques, and monitor the temperature and humidity changes over a relatively lengthy period using remote sensors.

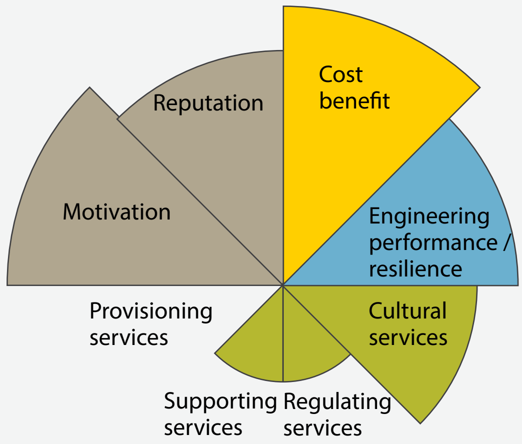
Design Innovation / Enhancement measure

The wall head of historic ruins was protected using a combination of the geotextile and clay/ sand mix topped with turf. The design enabled conservation of vulnerable masonry by maintaining a relatively stable temperature, humidity and pH. Monitoring was incorporated into the activities, by burying iButton sensors at different depths within the reburial material (at 20 mm, 70 mm and 150 mm depths, and between the masonry and membrane).

image ©Historic Environment Scotland

Benefits

The technique appears to provide a stabilising option that can drastically limit the rate of degradation of important social, cultural, historic and economic historic conservation structures. This could be a useful and cost effective way to preserve cultural and historically significant buildings in the long term. It also has the potential (as yet unmeasured) to improve climate change resilience of the assets and through improved rainfall attenuation, as well as improve habitat for wildlife. Modern scanning and mapping technologies can create detailed 3D images of the structures for analysis and public engagement, and if required, the capping can simply be removed later.



Net Cost

The net cost of the intervention is expected to be very similar to the direct cost of the reburial construction costs, as on-going inspection and maintenance is expected to be low and the turfed areas to have a long (> 25 year) design life. For this trial, there are additional monitoring costs to evaluate the effects of reburial on the risk of subsurface deterioration. These increase the net cost of reburial in this instance.

Cost compared to business-as -usual

The direct cost of the intervention was £22,000 (2015 costs) compared to £120,000 for consolidation repairs to the historic asset, which was the second option considered during the options appraisal. This represents an 82% savings for design and construction compared to business-as-usual, a savings of £1151 per m^2.

Direct cost of intervention

The direct cost of the intervention was £22,000 (2015 costs) of which £18,000 was labour and £4000 was material costs, including VAT for the design and installation of 66m^2 of reburial works. The cost per m^2 is £667.

Long-term cost

The long-term asset maintenance costs of reburial are unknown but are expected to be low. Historic Environment Scotland are monitoring the reburial to measure the effects of reburial on soil moisture fluxes and thus risk of asset deterioration, which is incurring a modest cost.

Engineering performance, inspection and maintenance

The reburial/capping provides a stable environment relatively free from damaging influences. The dense materials provide thermal stability, insulating the masonry from temperature extremes, intense and chronic exposure to radiation, storms and other extreme weather events.

The Jedburgh work included the use of iButtons – remote sensors that monitor the environmental conditions. Data from the iButtons will be analysed for changes in environmental conditions like thermal variation and humidity changes.

Ecosystem services

The vegetation capping the reburial will provide a modest amount of habitat that can be mowed or left to develop into more mature grassland. There are opportunities to plant wild flower meadow species and provide opportunities for other wildlife, including late pollinators that may not have access to suitable habitat elsewhere. Initiatives to link pollinator habitats include B-lines and the National pollinator Strategy.

Because of the scale and nature of the sites, there may be limited capacity to enhance ecosystem services beyond a local scale, although they may form part of larger strategic enhancement work. Supporting services might be achieved by creating a soil layer and vegetation that plays a role in nutrient cycling and primary production. The grass habitat can provide some regulating service including carbon sequestration and runoff reduction / water storage. Cultural services will be enhanced in the long-term by the improved lifespan of the historic assets, but reburial makes them inaccessible in the immediate term.

Social value

Reburial is proving a cost-effective method for vulnerable historic ruins, conserving them for future generations as a more sustainable solution to on-going decay of valuable assets that are under increasing threat from environmental change. Reburial may be controversial – removing access to monuments by the general public. Education opportunities exist to convey the conservation value of this approach, but information is not available on public opinion about reburial, although anecdotal evidence suggests it has generally been viewed very positively. Digital technologies (such as high resolution scanning prior to reburial) offer significant opportunities to overcome some of the challenges; interactive 3D models could be produced to aid education and interpretation and to conserve public 'access' to the buried asset.


image ©Historic Environment Scotland

Who can apply this intervention / technique?

Anyone looking to conserve degrading masonry structures, and where alternative conservation strategies are not possible or appropriate. The burial techniques are reasonably straightforward and the materials widely available. It is important that specialist guidance is taken if deciding to rebury protected historic assets. Digital preservation of assets prior to reburial is highly recommended, and for this additional funding and expertise will be required.

Scaling up the benefits

There are a great number of historic monuments, ruins and masonry walls that might benefit from reburial, especially were alternative conservation approaches are deemed unsuitable and / or where funding is very limited. For public assets, ensuring people are engaged and educated about the purposes and benefits of reburial will be important if this is to be adopted more widely as a strategy.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
COST			●				
ENGINEERING			●	●			
ECOSYSTEM		●		●			

Further information / Contacts

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Morton, T. et. al. (2011). Soft capping in Scotland: the content and potential of using plants to protect masonry, Historic Scotland Research Report. URL: https://www.engineshed.org/publications/publication/?publicationId=5a2c8f33-dc6a-4604-9df6-a5af00960d7b

National Pollinator Strategy (2015). https://www.gov.uk/government/publications/national-pollinator-strategy-2014-to-2024-implementation-plan [Accessed August 2017].

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Historic Art of the Possible

Art of the Possible

Soft capping of Historic Walls in Fife, Scotland

HISTORIC

AP-H1

images ©Historic Environment Scotland

What is the measure?

Vegetation and growing medium applied to the top of historic wall to provide sustainable and low intervention improved resilience. Local clay and sand mortar mix is applied to historic ruin wall tops and capped with local turf and sedum. Trialled by National Trust for Scotland with funding from Historic Environment Scotland at Balmerino Abbey, Fife.

Primary Driver

To adopt a low impact and sustainable method of protecting the underlying masonry and wall core, reducing the risk of damage from water penetration at high level. Roofless and ruinous monuments can be at risk of erosion and damage from increased rainfall. Sustained saturation through the wallhead can result in loss of structural integrity and disfiguration due to lime-binder leaching through the wall core. Soft capping is a low maintenance, non-destructive, reversible, sustainable and visually pleasing alternative to the business as usual rough racking (stone and mortar) technique.

Benefit

Straightforward and relatively inexpensive measure which mimics natural soft-capping, providing low maintenance and visually pleasing protection to roofless monuments requiring minimal intervention. Soft capping ameliorates the effects of exposure and erosion, improving resilience, and protecting the monument from the effects of climate change.

Cost

Materials for soft capping are low-cost (see CS-H1) and may be sourced on site or locally. Sand and turf are readily available as are plug plants which are used to stabilise the turf. However time for preparing clay, applying on site, finishing and protecting can increase labour costs compared to conventional rough-racking. Success can be weather dependant and more watering is required during dry or warm periods. Both green and business as usual methods require routine maintenance and inspection.
Long terms cost benefits are anticipated to be significant as the soft capping matures and stabilises requiring less maintenance, and the protection afforded to the wallhead reduces the risk of damage to the monument.

Engineering

The resilience of the wall can be increased with the introduction of the soft cap. Vegetation can reduce thermal flux, shade against sun-damage and reduce frost damage and wind erosion. Where soft capping is maintained and performs well, water ingress is reduced and resulting damage avoided. Soft capping may not be suitable for very dry or drought-prone sites.

Asset Resilience

Well maintained soft capping can reduce climatic impacts. Using living plants and clay/soil provides a water resistant layer that acts as a buffer which protects the masonry from penetrating damp and cyclical wetting and drying, freeze/thaw cycles.

Ecosystem Services

Soft capping can improve biodiversity on historic sites and reduce water run-off from wallheads, improving site water management.

Social

Historically, ruins with natural soft capping have been appreciated for their beauty, demonstrating a visually pleasing harmony between the built and natural world. Both naturally occurring and applied soft-capping can soften the appearance of a ruined structure and improve the visual appearance of the site.

Policy

Use of soft capping on monuments can help meet Scottish Government targets and public body obligations related to enhancing biodiversity and use of sustainable materials.
It also supports the Scottish Adaptation Framework set up improve Scotland's resilience to the climate change.

Further information

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Art of the Possible

Soft capping of Historic Walls in Bothwell, Scotland

HISTORIC

AP-H2

What is the measure?

A clay capping topped with turf was added to the top of historic wall to provide sustainable and low cost intervention, serving as form of adaptive (proactive) conservation. Clay and sand mix is applied to historic ruin wall tops and capped with turf incorporating sedum plants to edges. It was installed on a length of the curtain walls at Bothwell Castle, Scotland in 2013.

Primary Driver

Climate change is forecast to increase rainfall in central Scotland, which may increase the rate of deterioration of historic monument assets of high cultural value. Sustained saturation through the wallhead can result in accelerated masonry decay and loss of structural integrity. Traditional rough racking capping methods are expensive to implement and maintain and they deteriorate quickly (c. 25 year design life). Soft capping is a low maintenance, reversible, sustainable and visually pleasing alternative method of protecting the underlying masonry, reducing the risk of water penetration damage.

Benefit

Straightforward and relatively inexpensive measure which mimics natural vegetation colonisation, providing low maintenance and visually pleasing protection to roofless monuments requiring minimal intervention. Established soft capping is self-sustaining like an untended meadow and ameliorates the effects of exposure and erosion, improving resilience, and protecting the monument from the effects of climate change. It also reduces the need to regularly inspect for loose rough racking stones and the potential hazard they pose.

Cost

Materials for soft capping are low-cost and easily sourced - sometimes locally. Sand, turf, plug plants and pegs are used to establish soft capping on wallheads. However preparing wall heads masonry to receive, working clay, applying on site, laying turf finishing and protecting are all labour intensive, and access scaffold costs need to be factored in.

Long term cost benefits are anticipated to be significant as the soft capping matures and stabilises requiring less intensive maintenance than rough racking methods (which need periodic maintenance and full replacement every ~25 years), and the protection afforded to the wall masonry reduces deterioration risk and associated maintenance needs.

Engineering

The resilience of the wall can be increased with the introduction of the soft cap. Vegetation can reduce thermal fluxes, frost damage and wind erosion. Where soft capping performs well, wall head water ingress is minimised and run off down wall faces is reduced protecting historic masonry. Maintenance of the soft cappings are less expensive than for rough racking and involve periodic inspections to remove woody species which can usually be done without incurring the scaffold costs rough racking overhaul entails. Maintenance needs in the 5 years since installation at Bothwell have been less than anticipated.

Asset Resilience

Well maintained soft capping can reduce climatic impacts on ruined structures. Observational evidence from this site suggests that the walls are drier using soft capping compared to conventional rough racking methods.

Ecosystem Services

Soft capping can improve biodiversity on historic sites and slow water run-off from wallheads, has potential to marginally improve site water management. They also help sustain cultural ecosystem services (see social).

Social

Historically, ruins with natural soft capping have been appreciated for their beauty. Soft capping helps conserve and sustain historic structures by stemming decay so their cultural (national identity, community and tourism) value can continue to be enjoyed and appreciated by future generations – national identity value, community value and tourism value. See comment above hazard inference.

Policy

Use of soft capping on monuments can help meet Scottish Government targets and public body obligations related to heritage conservation, enhancing biodiversity, sustainability and improving Scotland's resilience to the climate change.

Further information

Hyslop, E. (2014). Climate Change Adaptation in Historic Scotland: First Steps. URL: https://www.adaptationscotland.org.uk/application/files/1614/7094/7071/2014_ALE_workshop_HistoricScotland_presentation.pdf

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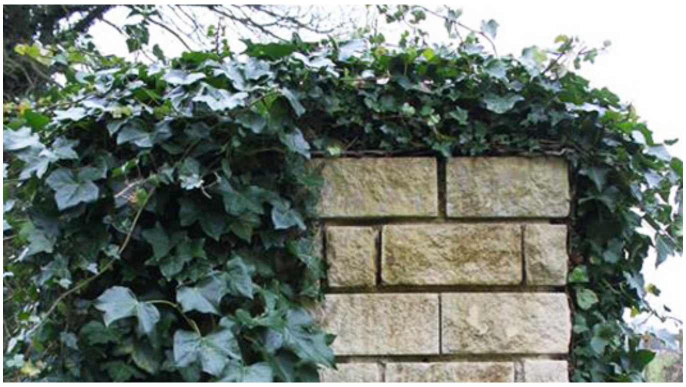
This forms part of Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Art of the Possible

Ivy on Historic Walls



What is the measure?

This is a new way of thinking about ivy growing on historic walls and buildings. Rather than automatically removing it under the assumption it is always damaging, there is now strong evidence to suggest that–where managed sensibly–ivy can provide benefits for asset resilience alongside other environmental gains.

Primary Driver

Ivy often colonises old walls and ruins naturally over time, and there is a general assumption that it is always damaging and should be removed. This can be costly to do and, in some cases, can make the situation worse. Research has been carried out to assess when ivy is likely to be bad (and should be removed) and when it can be good and should be left/managed to avoid costly removal and help protect walls from other agents of deterioration (e.g., frost).

Benefit

Largely dependent on nature of the structure (especially its current state of repair), type of growth, existing risks and management practice. Likely to be highly case-specific.

Cost

A research project by the University of Oxford, funded by Historic England, built stone and lime mortar test walls (c. £5k) using traditional construction methods. On four different aspects (N, S, E, W) ivy was grown up one side of the wall and the plant's interaction with the materials was monitored over several years. In most instances, ivy colonises naturally and therefore no costs are involved. Alternatively, it could be planted intentionally, with minimal cost. Any ivy will require maintenance – it should be trimmed regularly to keep growth under control.

Engineering

For masonry structures that are in a good general state of repair, and where appropriate steps are taken to manage the plant, ivy will have minimal/negligible risk to the structure. Ivy has no capacity to 'bore in' to a wall unless there are already existing defects. Where ivy is already well established, care must be taken if deciding to remove it – where it is growing into the fabric of assets in very poor condition, the plant may be contributing to the stability of the structure. A covering of ivy can make structures more difficult to inspect and so targeted removal (in small patches) may be needed to do this.

Asset Resilience

A cover of ivy may help extend the life span of the asset by reducing rates of weathering (caused by heating-cooling, wetting-drying, salt crystallisation and frost) relative to bare walls. It can also act as an effective anti-graffiti measure. Monitoring on the test walls showed that physical deterioration was no faster under a cover of ivy over a period of 3 to 4 years.

Where it is not deemed necessary to remove ivy, it should nevertheless be managed. Annual/biennial trimming to keep climbing/clinging stems away from gutters, window frames, roof slates, and coping and caps is important.

Ecosystem Services

Ivy is very important for biodiversity, especially in urban areas where (evergreen) cover for nesting birds can be limited. Ivy is particularly attractive to insects (including bees) and is a valuable source of nectar and berries late in the season. Ivy should never be cut or removed without first checking for nesting birds.

Social

Where obscuration of architectural detailing is not a concern, a cover of ivy can enhance the aesthetic of a wall/building. A cover of ivy is often appreciated for adding a natural/romantic aesthetic to ruined sites, walls and historic buildings.

Policy

Local Planning Authorities make most decisions on managing heritage assets, though often under expert guidance. Historic England guidance on managing ivy on historic walls calls for careful evaluation of whether it should be removed or left. It should not be automatically assumed it is doing damage, and in many cases can be used as an interim or more permanent measures to help conserve vulnerable walls/buildings, as well as support local biodiversity.

Further information

Detailed information of the monitoring and experiments undertaken to evaluate the roles of ivy on walls is available from the Historic England research report:
Coombes, M.A., Viles, H.A., Cathersides, A. (forthcoming) Ivy on Walls. Historic England Research Reports Series.

Martin Coombes, University of Oxford: martin.coombes@ouce.ox.ac.uk, @MACoombes

This forms part of Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Art of the Possible

Ivy for Air Pollution

HISTORIC

AP-H4

What is the measure?

This was an experimental investigation into the effect of ivy foliage on air pollutants in a range of different settings in and around the City of Oxford, as part of a larger project on English ivy funded by Historic England. Ivy leaves were collected from existing plants on walls exposed to different levels of traffic pollution. Leaves were examined using an electron microscope and the number, size and density of particulate pollutants were measured.

Primary Driver

Traffic pollution in urban areas is a major issue for the conservation of historic buildings and structures, as well as for human health. Airborne particulates (e.g. those from combustion and traffic fumes) react chemically with stone in combination with rainwater. This can lead to surface blackening through the formation of unsightly gypsum crusts.

Benefit

Ivy was found to be an effective filter of airborne particulates from a range of sources including coal and diesel combustion. The number of particles on leaves was closely linked to traffic volume – more pollutants were trapped on ivy leaves where traffic flow was highest. In these cases particulate density was up to 30 thousand particles per mm^2 compared to leaves from a rural (low traffic) site with as few as 60 particulates per mm^2.

In high traffic areas, ivy foliage significantly reduced the amount of pollution reaching the face of the walls it was growing on – leaves closer to the wall face had significantly fewer particulates than those nearer the pollution source. In this way, ivy was found to be an effective filter of urban airborne pollutants.

Cost

This experiment was part of a research project by the University of Oxford, funded by Historic England. Costs involved researcher time for sampling and analysis.
Where it colonises naturally (which is common on historic structures) there may be no costs involved in growing ivy. Alternatively, it can be planted intentionally. In all cases, regular maintenance is essential given the potential for the plant to cause damage in some situations - see other ivy examples in the Historic Bundle.

Engineering

For masonry structures that are in a good general state of repair, and where appropriate inspection and maintenance measures are taken, a cover of ivy has low potential to cause structural damage.

Asset Resilience

With respect to air pollution, a cover of ivy can reduce rates of surficial weathering and discolouration. The significance of this will vary depending on the particular concerns for the structure in question e.g., whether preventing black crusting is a priority or whether obscuring a surface with ivy is deemed inappropriate etc. Some stone types like limestone are particularly vulnerable to black crust formation, meaning that using ivy as a protection measure may be more or less appropriate depending on the existing risks, as well as the current condition of the asset.

Where it is not deemed necessary to remove ivy, it should nevertheless be managed. Annual/biennial trimming to keep climbing/clinging stems away from gutters, window frames, roof slates, and coping and caps is important.

Ecosystem Services

Ivy has very important benefits for biodiversity in urban areas. It serves as an important source of nectar for insects and berries for birds late in the season. Ivy should never be cut or removed without first checking for nesting birds.

Social

The particulate filtering effect of ivy has two main social benefits: (1) it reduces potential damage to structures of heritage value caused by discolouration and surface crusting; (2) although not the focus of this experiment, ivy was found to be an effective filer of airborne pollutants indicating that it can contribute to improving local air quality in urban areas, especially alongside other measures such as traffic management and other forms of greening.

Policy

Local Planning Authorities make most decisions on managing heritage assets, though often under expert guidance. Historic England guidance on managing ivy on historic walls calls for careful evaluation of whether it should be removed or left. It should not be automatically assumed it is doing damage, and in many cases can be used as an interim or more permanent measures to help conserve vulnerable walls/buildings, as well as support local biodiversity.

Further information

Sternberg, T., Viles, H, Cathersides, A., Edwards, M. (2010). Dust particulate absorption by ivy (Hedera helix L) on historic walls in urban environments. Science of the Total Environment 409, 162-168.

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This forms part of Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Appendix 2: Urban

This appendix is one of four environment topics covered as part of the NERC funded project report: Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Business case: Urban innovations

This business case assesses the existing evidence of integrated green grey infrastructure (IGGI) measures that can support wider implementation of integrated green grey infrastructure in urban and peri-urban areas. The IGGI measures assessed here are not typically part of GI policy or are emerging solutions that can deliver GI solutions in confined urban spaces where more traditional GI such as parks and sustainable urban drainage systems are not feasible. Costs, benefits and measures of the engineering and ecological performance (called critical success factors) of a range of IGGI alternatives to traditional, hard engineered projects are drawn from operational and research examples across the UK and beyond. They illustrate the range of IGGI measures and IGGI solutions that could be applied in cities, housing developments and light industrial areas in the UK.

The business case contains an overview of what the measures are, and how and where they can be implemented. It is aimed at reducing the uncertainties practitioners have identified when considering GI innovations, including:

- What are they?
- Where have they been applied?
- What evidence is there to show they work well?
- Costs
- What are the benefits over business-as-usual?
- What measures and solutions are there?
- Where are they suitable?
- What are the risks?
- Approval
- What are the wider corporate benefits?

As urbanisation increases, more sustainable alternatives are being developed to improve the multifunctionality and resilience of infrastructure and urban environments. The examples below show innovative techniques that integrate natural solutions onto grey infrastructure that can provide additional benefits compared with traditional grey infrastructure.

What are they?

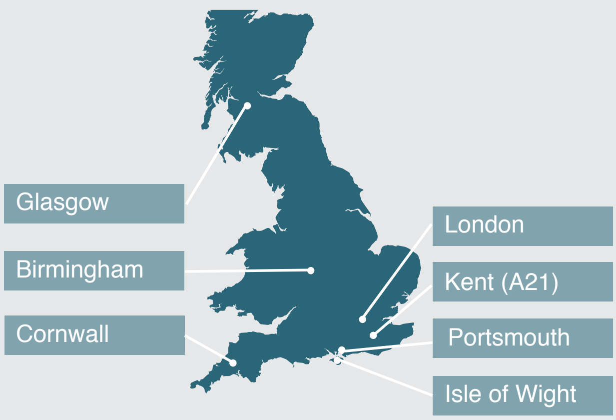
Urban IGGI measures involve changing operational practices at design, construction and monitoring phases to explicitly improve the ecosystem services and thus the multifunctional capacity of our infrastructure for society. They are often simple and inexpensive to design-in or retrofit such as altering the structural fabric of assets by replacing traditional bricks or park benches with microhabitat features; installing green screens along guard rails and fences to improve air quality, amenity and ecological value. We can also alter management plans, e.g. reduced mowing of verges to encourage pollinators. These IGGI measures can usefully extend the range of GI solutions for small urban spaces considered in citywide, national or international strategies to create, enhance or link habitats. They have been applied at any stage, from helping achieve planning consents, to altering installation practices, designing in and/or retrofitting habitat enhancement and; modified repair and maintenance plans.

Through practitioner support, we have identified a number of critical success factors that are used to assess the motivation, engineering, geomorphology, ecosystem services and social value of these IGGI innovations as well as their policy drivers. Relevant data, supporting data from other studies and expert opinion was used to assess how these urban IGGI innovations perform compared to traditional, grey engineering solutions.

When in the design/life of an asset can they be applied?

The measures described here can be applied at any stage of the design life of infrastructure. Many have been tested as retrofits or were added-in later in the design phase of projects, but it may prove more economical to design them in from the start of maintenance and/or new build schemes such as the growing number of initiatives applying GI in small spaces or to deliver net ecological gain.

Where have they been applied?



Evidence Summary

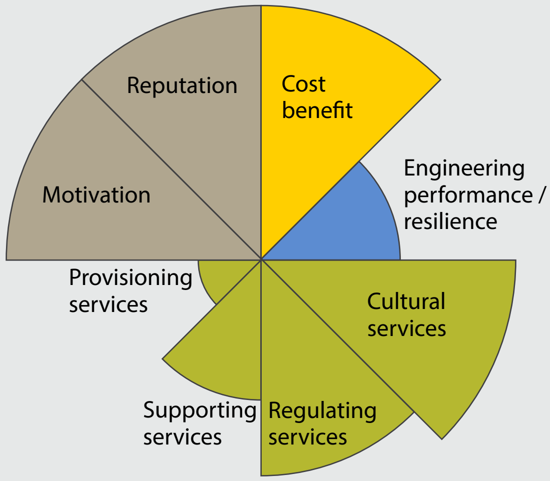
This summary provides an overview of the evidence derived from the urban case studies and "*Art of the Possible*" examples; these are existing IGGI measures that have been applied across the UK. Many of the IGGI examples within the historic, mowing and coastal can also be applied in urban areas.

Costs	Ecosystem Services	Engineering	Policy
What do they cost compared to business-as-usual?	What evidence do we have that they deliver ecosystem service benefits?	Are there any risks to design life, inspection or effects on maintenance regimes?	How does it relate to policy and guidance?
The costs compared to business-as-usual varied by type, with most being the same or having some additional cost over business-as-usual (apart from CS-U2 and AP-U2 which were less expensive)	Typically to improve air quality, biodiversity and/or amenity value in dense urban areas. Limited evidence but could be valuable GI in more densely urbanised areas.	If properly designed and installed there is little or no impact on engineering performance, and for some examples there are limited additional or alternative inspection/ maintenance requirements.	They have been used to help deliver biodiversity, air quality and/or net ecological gain targets; local development policy has also been changed (AP-U4).
LESS - MORE	POSITIVE	NEUTRAL	ACHIEVED

Data Quality	Social	Reputation	Asset Resilience
What is the quality of the data underpinning this bundle?	What are the potential additional social benefits - jobs, cohesion, education etc.?	How have the schemes helped improve public perceptions?	Is asset resilience affected, neutral or improved?
Ecology and air quality related data was typically of moderate data quality for case studies; other data types varied.	High potential to improve urban ecology (CS-U1, CS-U2), human wellbeing (AP-U6) and economic activity in dense urban areas.	Improved corporate reputation and increased public support for most examples. Some examples were shortlisted for awards (CS-U2, AP-U2).	Some examples have a shorter design life compared to business as usual; however the IGGI measures were cheaper and provided more benefits compared to business as usual.
MODERATE	UNKNOWN - POSITIVE	NEUTRAL - POSITIVE	UNKNOWN

Benefits Assessment

The evidence summary presented above is derived from the examples contained in this bundle, each of which have been assessed using the Critical Success Factors guidance developed by this project. The benefits wheels show the benefits of each critical success factor relative to each other. They are a combination of ecosystem services and other important considerations necessary to evaluate IGGI measures compared to business as usual. More detailed breakdown of each element of each can be found below.



Cost

While inclusion of most IGGI measures did increase direct costs, this was often a small percentage of the overall construction cost. Some measures had similar or reduced construction costs, but where maintenance or repairs may increase compared to grey engineering options. For these, the whole life costs are likely to be less or the same as the grey engineering solution (CS-C2, AP-U2) but with wider ecosystem service, social and reputational benefits. All measures were found to provide (or have the potential to provide) value for money, with additional value gained from enhanced ecosystem services, helping meet statutory mitigation requirements or net ecological gain, by providing social benefits and/or additional returns compared to traditional grey engineering.

The IGGI measures presented here can provide cost effective, multifunctional solutions to long-term and increasing urban environmental issues such as air pollution regulation, climate change adaptation and the need to deliver ecosystem services within cities.

Engineering value

The urban IGGI measures presented here have little or no negative effects on engineering performance. Where design life is expected to be shorter than business as usual grey engineering options (e.g. CS-C2, AP-U2), the construction costs were substantively cheaper for the IGGI option which means the whole life costs are unlikely to higher when choosing an IGGI option over a traditional grey engineering approach.

Cultural services

Some IGGI measures were expressly and successfully designed to improve cultural services in terms of landscape character (CS-U1), wellbeing (CS-U4), amenity (CS-U3) or social cohesion (AP-U3). The cultural service values provided are typically high for those where this was measured; there is widespread potential for all urban IGGI measures to provide cultural services.

Regulating services

The examples presented here have been successfully designed to provide local scale regulatory services such as improving local air quality by trapping harmful pollutants (CS-U3, CS-U4, AP-U6, AP-U7), by attenuating rainfall runoff (AP-U1) and by reducing the local impacts of the urban heat island (AP-U7).

Provisioning services

The urban IGGI measures presented here provided little or no provisioning services. However, there is potential for these measures to be adapted to target provisioning services (e.g. edible bus stops).

Supporting services

Several measures have improved habitat for key pollinators such as bees (AP-U3-5), enhanced biodiversity compared to grey alternatives (CS-C2, AP-U1-2) through habitat provision, and also serve to improve ecological connectivity for priority species (CS-U1, AP-U1).

Motivation

IGGI measures can provide significant returns on investment and address the issues that motivated their implementation (e.g. statutory mitigation), by providing useful habitat, public engagement, air quality and/or aesthetic benefits.

Policy

Some innovations have led to changes in local development policy to require habitat enhancements (AP-U4), or are now routine practice in urban areas in Germany (AP-U1). Most examples can be used to deliver net ecological gain and/or local biodiversity targets (CS-U2, AP-U2).

Reputation

The ecological and social benefits of these IGGI measures can help improve the reputation of local councils, asset and landowners.

IGGI Measures

IGGI measures showcased in this project were derived from a combination of expert knowledge, information requests and searches. UK information was requested from key project partners including government agencies and local government staff. These examples were categorised into detailed, relatively evidence rich and operationally applied case studies and 'Art of the Possible' examples which either have limited data or were drawn from academic research where they have not yet been applied operationally. Each measure was categorised and numbered as a case study (CS-U1 to CS-U4) or 'Art of the Possible' (AP-U1 to AP-U7). During the research and data gathering phase of this project, many innovations were identified that have been built as urban IGGI. These examples have little or no data, so are presented as short thumbnail sketches illustrating what they are and where they have been built. These are to provide further ideas of the range of IGGI innovations that are possible and could be applied more widely than to date.

What measures are there?

Case Studies

Aim of the IGGI	Label	Title
To maintain landscape character and improve ecological connectivity between areas of high conservation importance.	CS-U1	Green Bridge
To improve the biodiversity value of railway embankment structures; conversion from industrial waste processing site to more ecologically valuable use.	CS-U2	Green railway embankment
To intercept and trap vehicular-derived pollutants and protect the health of road users, particularly pedestrians	CS-U3	Green Screen Guard Rail
To intercept and trap vehicular-derived pollutants and protect the health of the schoolchildren and staff.	CS-U4	Green Screen School

Art of the Possible

Aim of the IGGI	Label	Title
To install green track beds in order to improve amenity, wildlife, pollutant trapping and water infiltration.	AP-U1	Green Tram
To replace low-biodiversity hard assets and invasive woody vegetation with addition of green walls and geotextile membranes in order to reduce maintenance costs and increase wildlife value.	AP-U2	Green Railway Walls
To create of bee habitat in order to improve community engagement with the local environment.	AP-U3	Bee Walls
To create habitat for solitary mason and leaf cutting bees.	AP-U4	Bee Bricks
To create of habitat for bees and nectar-providing plants	AP-U5	Bee Benches
To improve of air quality both outside and inside local NHS facility	AP-U6	Trees for Health
Local scale air pollution and urban cooling via a vertical greening system on street furniture.	AP-U7	City Tree

IGGI Solutions

IGGI measures from across all four bundles can be combined in urban landscapes so that greening of the grey can occur across the landscape from the coast through our cities and towns to the peri-urban fringe. For example, at the scale of an individual scheme, IGGI measures could be combined to improve ecosystem service provision such as by placing bee walls (AP-U3) alongside reduced mowing regimes (Mowing bundle) in order to increase bee populations and overall biodiversity.

Urban IGGI measures may be combined with each other or with more established types of green infrastructure to help optimise the ecosystem services provided. The London Ecology Masterplan highlighted in the main report provides a good example of how IGGI measures could enhance greening planned for buildings in central London at a strategic scale. The IGGI measures listed in this bundle can also be used to help add green features to the growing number of greet street initiatives that are emerging in the UK and beyond, and support the Linear Infrastructure network's initiative to show how green infrastructure can enhance infrastructure resilience (Natural England, 2017). At the scheme scale, it is also possible to combine IGGI and other GI infrasutructre to improve benefits such as the installation of bee benches (AP-U5) around SuDs retention ponds or the use of green screen guard rails alongside street trees to capture pollution at a range of heights.

The diagram below enables visualisation of how different measures may be combined, and shows the urban greening benefits that can be achieved by adding the IGGI measures from the urban and coastal bundles to help 'green the grey'.

Where are they suitable?

They can be applied in almost any urban or peri-urban setting has enhancement potential for the measures contained in this bundle and the associated mowing bundle. The examples here have been used in deprived areas to enhance visual appeal, in aesthetically appealing areas for planning approval, in polluted areas, in under-used areas to increase footfall and in very busy areas to reduce the visual impact of hard-engineered infrastructure.

What ecological factors need to be considered?

It is important to consider the ecological suitability of the IGGI measures for a given location and for different types of urban IGGI assets and their component materials. Timing of application, the kinds of species used and maintenance practices can influence the likely success of greening measures and their ability to support beneficial biodiversity and/or to provide regulating services such as air quality or temperature regulation. Similarly, given that the measures described in the bundle are primarily intended to aid conservation of the assets, biodiversity gains are only a secondary aim and may be generally limited, but can be locally significant. Further details of these kinds of considerations are provided on the risks page of this business case.

How can you get this type of greening approved for your scheme?

The case studies, art of the possible examples and policy links provided here can be used to demonstrate the economic, environmental and social benefits that can be gained from adding IGGI measures to urban projects. Each case study and art of the possible detailed here was designed to help address an issue of air quality, visual impact, community engagement and/or biodiversity. Many IGGI measures address more than one policy area. In offering sustainable, multi-benefit solutions to issues that are growing within urban areas (that are also increasing), urban IGGI measures can help meet a wide range of policy, plan and guidance goals. For example, they provide clear evidence of the policies that have been used to meet local biodiversity targets (CS-U2, AP-U2), landscape character requirements (CS-U1) to help shape local policies (AP-U4) or non-statutory, organisational strategy (AP-U6) drivers. Where no statutory mitigation is required, how else can you get this type of greening approved? Many of the examples only require a willingness to innovate, as testing or applying IGGI measures often requires minimal change in behaviour or practice. Others provide direct cost savings at the time of construction (CS-C2, AP-U2) or provide wider benefits such as community engagement for a similar cost to business as usual options (AP-U5).

What are the risks?

There is increasing evidence of the multifunctional benefits of IGGI measures for a range of urban infrastructure assets including transport infrastructure, freestanding walls and guardrails, street furniture and pavements. As with any engineering solution or urban planning decision, there are trade-offs between risks and benefits associated with different options. As urban IGGI is a new and growing field, there is a need to clearly identify known risks and limitations emerging from research and best practice exemplars. The risks and limitations associated with the urban IGGI measures described in the bundle include:

Known limitations or risks associated with these IGGI approaches

Risk Factor	Description and Risk Reduction Strategies
Biodiversity	There is little data regarding the effects IGGI measures have on urban biodiversity. It is likely that an increase in vegetation and/or habitat provision in the urban environment would result in higher levels of biodiversity, as some of the urban IGGI examples show. Further study would be required to validate this more widely.
Ecological connectivity	It is also important to ensure that where nesting habitats are added (e.g. AP-U4-5) that suitable, nearby feeding habitat is also created (e.g. AP-U3). It is also important to evaluate how these innovations can be optimised to ensure they improve ecological connectivity and do not negatively impact upon other local species.
Geography	Care ought to be taken to ensure the sites chosen are suitable for the selected IGGI measures. For example, roadside greening will require species which are resistant to both wind and vehicle pollution.
Design	It must be ensured that any IGGI measures have the appropriate design, as poor designs may exacerbate environmental issues. For example street trees that are inappropriately spaced and/or too tall may lead to an increase in local pollutant concentrations, especially particulate matter. It is also important to try to achieve multifunctional uses of urban IGGI wherever possible, including combining them with SUDs.
Timing	It is particularly important to time construction of IGGI measures in the main growing season so that the chances of early colonisation and establishment of target species is achieved, to reduce the risk (and removal costs) of any invasive species which establish due to poor timing (e.g. AP-U2).
Visibility	Any roadside greening must not impact upon the visibility of road users, be that pedestrians, cyclists or drivers. Suitable species must be appropriately positioned in order to reduce any potential visibility related hazard.
Maintenance	Routine maintenance would be required in order to maintain urban IGGI measures at their desired level. Again, this is particularly important for roadside measures as badly maintained greening systems may become hazardous and/or increase maintenance costs.
Scale	There is potential for widespread application of urban IGGI approaches across a range of infrastructure types. The main limitation is the space available to implement these measures.

Where to learn more

CIEEM (2016). Biodiversity net gain (CIRIA Biodiversity Net Gain – Principles and Guidance for UK construction and developments (RP1048))
URL: https://www.cieem.net/biodiversity-net-gain-principles-and-guidance-for-uk-construction-and-developments

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Landscape Institute (2015). Green Bridges Guide. London: Landscape Institute.
URL: https://www.landscapeinstitute.org/wp-content/uploads/2016/01/TGN9_15Green-Bridges-Guide_LI-300dpi.pdf

Metro Vancouver (2015). Connecting the dots: regional green infrastructure network resource guide.
URL: http://www.metrovancouver.org/services/regional-planning/PlanningPublications/ConnectintheDots.pdf

Naylor L., Coombes M., Kippen H., Horton B., Gardiner T., Cordell M.R., Simm J. & Underwood, G.J.C. (2017). Developing a business case for greening of hard coastal and estuarine infrastructure: preliminary results. Proceedings of the Institute of Civil Engineering. Paper 85, pp.1-11.

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Weerakkody, U., Dover, J.W., Mitchell, P., Reiling, K. In press. Particulate Matter pollution capture by leaves of seventeen living wall species with special reference to rail-traffic at a metropolitan station. Urban Forestry and Urban Greening.
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Urban Case Studies

Case Study CS-U1:

Green bridge

Summary

This green bridge maintains a pre-existing historic approach to Scotney Castle (Grade I Listed) and provides an access link in an Area of Outstanding Natural Beauty, over a dual carriageway by-pass around Lamberhurst village in Kent.

Benefit	Medium
Engineering	Low
Ecosystem	Medium
Direct Costs	Medium

How does it work?

The 92m long bridge spans a section of the 3.2km long dual carriageway through the historic area around Scotney Castle and is registered under the Historic Buildings and Ancient Monuments Act 1953 within the Register of Historic Parks and Gardens by English Heritage for its special historic interest (see Historic England National Heritage List for England website below). The bridge incorporates the historic West Drive – a feature of the 1837-43 redevelopment.

Motivation

The initial plan to upgrade the A21 divided the picturesque landscape and interrupted an historic approach to Scotney Castle. The green bridge provided mitigation for this and met statutory needs for Highways England and Natural England to protect and enhance the landscape and biodiversity, and to promote conservation and wildlife.

Design Innovation / Enhancement measure

This is one of a handful of green bridges built in the UK and the only one built largely to address landscape issues – to retain connectivity between Scotney Castle and the West Lodge and the original access drive. It is part of an Area of Outstanding Natural Beauty and the site is Grade I Listed. The castle and grounds contain many of the features planned between 1837 and 1843 by Edward Hussey III (and landscape designer William Sawrey Gilpin). The green bridge design had to balance the functional engineering requirements including horizontal and vertical alignment, whilst providing a wildlife corridor. The wildlife corridor had to include native planting that matched local variations and reflected the qualities of the landscape, and incorporated exotic species used in the original ground planting in 1842.

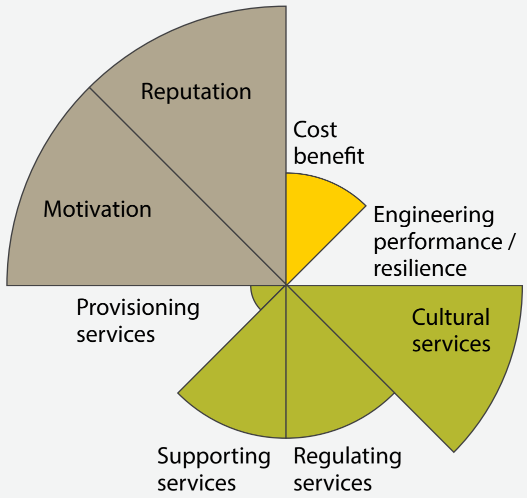
Photo Credit: Natural England

Photo Credit: Natural England

Benefits

Though details are not available as to the extent, the green element undoubtedly will have increased the project cost compared to a more standard bridge. However, the sympathetic design and construction will mean the cultural and aesthetic value of the area is maintained, and because of this continued appeal of the area could be ascribed some financial value – visitors, property prices etc.
The green elements of the bridge will provide some modest rainfall attenuation and soil production ecosystem services though it was as not design explicitly to do so.

In fulfilling the remit to provide an environmentally sensitive connection over the highway the Scotney Bridge has been considered a success and functions well.



Net Cost

Only the whole scheme construction costs of £22M for the A21 upgrade are available; it is not possible to determine what percentage of this the green bridge cost.

Direct cost of intervention and cost compared to business-as-usual

The additional cost of providing the green elements are not available, such as for the additional engineering materials and time, plus the growing medium and plants. The costs of green bridges built in Europe can be found in a recent Natural England (2015) report.

Long-term cost

By maintaining a historic route to Scotney Castle in a sympathetic way, the bridge has helped maintain the landscape, heritage and tourist value of the area – the benefits from which can, in the long term, hopefully offset the increase in construction and maintenance costs compared to business as usual.

Engineering performance, inspection and maintenance

One of the key engineering design elements was the hour-glass shape of the bridge which allowed greater soil depths and mature vegetation at 'either end' which helped 'bed' the bridge seamlessly into the historic landscape and improved habitat provision.
Green bridges are currently rare in the UK, where related design guidance and extensive evidence of their engineering performance is available from Europe and Canada. The inclusion of soil, habitat (sometimes considerable large vegetation/trees) and water retention features add complexity and additional factors to be considered but these appear not to be intractable engineering issues.

Ecosystem Services

In an attempt to recreate a more mature environment the bridge was planted with a continuous vegetation cover of varying width (between 3m and 10m) and populated with sections of log and moss planting. A minimum of 0.6m to 1.5m of locally won subsoils and topsoils were used to cover the bridge. Much consideration was given to sourcing plants thought to be most appropriate, e.g. using exotics to replicate the fashionable redevelopment in 1842.

The bridge is unusual in that it was designed and installed largely to mitigate for potential damage to cultural heritage - namely the truncation of a historically important route, the "Drive" from the Castle to the West Lodge. It was designed to provide an aesthetically sympathetic solution and a more appealing alternative to the traditional hard grey alternative. The bridge construction also improved recreation, tourism and the local economy.

Large roads such as the A21 are known to create barriers to wildlife. Ecological monitoring was undertaken by the National trust, as part of the National Dormouse monitoring programme; they found breeding dormouse populations on the bridge within 5 years of installation. Bat surveys were also undertaken (ten surveys, six at dusk, four at dawn) and at least 5 species of bats were recorded where 97% of bat flights across the road were taken 'using' the bridge compared to open areas. Bats were also found to forage on the bridge.

In addition, the increased habitat will influence the water cycling locally. The bridge has a catchment collection system for rainwater, rainwater runoff from the east and west of the bridge pools and is delivered into a ribbed central reservoir on the land bridge, helping attenuate rainwater and water the bridge vegetation.

Social value

The scheme received a commendation at The Landscape Institute's 2007 Awards. For landscape, aesthetic, historic and economic benefits see above.

Who can apply this intervention / technique?

There are a few UK guidance documents on screening, planning and designing a green bridge – most refer to linking habitats, not designing for individual species, the importance of considering the impacts at a landscape scale and the need for the bridge to be part of a wider mitigation strategy.

Native mammals like deer and non-natives like wild boar can break through highway perimeter fencing and risk being hit by vehicles, causing vehicle damage, potentially fatal human injury and long traffic delays on key routes. Elsewhere bridges designed for wildlife can reduce the cost of installation, inspection and subsequent maintenance and repair costs of wildlife fencing as well as vehicle collision induced costs and delays.

Scaling up the benefits

There is growing interest and planning of green bridges in the UK; demonstrators like this case study are important to help show the potential benefits for people and wildlife, as well as economic drivers such as tourism, by building green bridges. There is capacity for more widespread application of green bridges in UK construction. More research on the cost –benefits and efficacy of green bridges to provide habitat links in different scenarios would help support wider implementation.

In the meantime, this case study and best practice guidance (e.g. Natural England 2015 and the associated Landscape Institute guidance) are useful resources to help identify possible desired outcomes and expected costs.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
COST		●		●			
ENGINEERING			●		●		
ECOSYSTEM SERVICES		●		●		●	

Further information / Contacts

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Contacts

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Case Study CS-U2:

Enhancing Railway Embankments for Wildlife

Summary

As part of works by the Thameslink Programme (TLP) to provide increased railway capacity through central London, Network Rail and Skanska UK improved conditions for wildlife at Bermondsey Dive Under by replacing poor condition, low biodiversity hard assets with wildflower planting of railway embankments and greening of freestanding walls (AP-U2). This case study discusses the wildflower planting of railway embankments only.

Benefit	Medium - High
Engineering	Neutral
Ecosystem	Medium
Direct Costs	More

How does it work?

The existing site contained debris, heavily contaminated soils with asbestos, hydro carbons and Japanese Knotweed. As a result, 21,900 tons of materials were removed and Knotweed was eradicated. Wildflower planting and green walls were installed to offset lost vegetation. Wildflower planting was also undertaken on 0.63 ha of railway embankments to create green corridors, to promote biodiversity and visual appeal.

For the planting, a wildflower mix was selected for native species and for low maintenance requirements including, for example, Field Scabious and Birdsfoot Trefoil and bee-friendly Cowslip and Yarrow. The wildflower was 'hydroseeded' using a nutrient mulch mixed with water, fertiliser and seed then sprayed in place. The mix protects the seed from adverse weather conditions promoting germination and supporting sward establishment.

Motivation

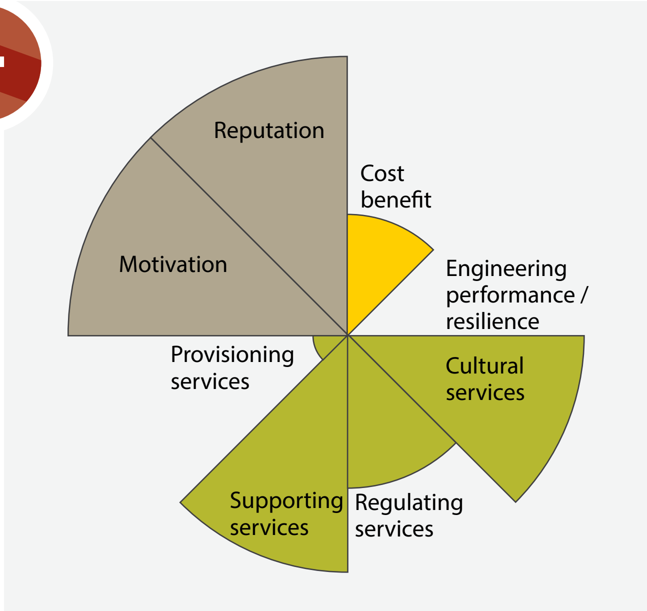
This site was undergoing a change of use from an industrial waste storage site to railway use. Mitigation was required due to the unavoidable impacts of the construction on the existing, low quality habitat. Ecological enhancements were made to the site through remediation, wildflower planting and the addition of green railway siding walls (AP-U2). This was designed to further enhance the site for wildlife and for visual amenity, helping deliver the required mitigation as well as net ecological gain on site. This approach meant no off site mitigation was required.

Design Innovation / Enhancement measure

To enhance existing low value and contaminated land for wildlife as part of larger infrastructure works to create net gain from the redevelopment. Several measures were carried out including green screens under arches and altered mowing and planting of access ramps and railway verges. This case study reports on the railway embankment component of the works.

Benefits

As well as achieving primary engineering goals, the intervention achieved additional environmental benefits. The planting supports the Lewisham and Southwark local authority's Biodiversity Action Plan (LBAP); wildflowers attracts insects, providing a valuable food source for birds and mammals recorded in the LBAPs including the red list species House Sparrows and Song Thrush, and 11 species of bats. Visual amenity of the site was also improved, although the direct amenity benefits were not measured. The IGGI measures met statutory mitigation requirements and delivered net ecological gain compared to the prior disused state of the site.



Net Cost

The whole life cost of the IGGI approach is unknown as the scheme is newly constructed and long-term maintenance costs whilst predicted to be minimal are unknown at this time. It is anticipated that the low maintenance soil type and hydroseeding will reduce maintenance, thus lowering the whole life cost making it more comparable to business as usual topsoil.

Direct cost of intervention

The gross material cost of alternative specification topsoil designed to reduce maintenance costs was £39,550. This compares with the original specification of £13,680, resulting in an extra cost of £25,870 (nearly double that of normal topsoil). Construction costs would otherwise have been the same.

Cost compared to business-as-usual

Due to the poor condition of the existing topsoil (contaminated and invasive species rich) and the need to choose a low maintenance topsoil designed to achieve the desired ecological goals, topsoil had to be imported costing an additional ٣٠£ per tonne compared to the original Class ٥B topsoil. However, the selected topsoil was designed to reduce or eliminate vegetation maintenance costs, so the long-term cost of the approach will be reduced compared to business-as-usual.

Long-term cost

Part of the reasoning behind the change to the low fertility topsoil was to discourage invasive fast growing species from invading. The topsoil was specifically selected to avoid the requirement for on-going future maintenance, meaning that whole life costs may be the same or lower than a more traditional construction technique.

Engineering performance, inspection and maintenance

Use of meadow planting has had no adverse effect on the performance of the asset and was the preferred option during options appraisal. Long-term maintenance costs are unknown due to the newness of the scheme, but planting was specifically chosen to minimise maintenance requirements, and to meet safety restrictions of vegetation height parallel to the railway. Use of low nutrient soil was intended to reduce management requirements relative to the 'normal' 300 mm topsoil as growth is less vigorous. The area will be serviced under the continual maintenance schedule helping the habitat mature and become ecologically valuable. The maintenance regime was produced with reference from Environmental Design Manual (see references) and the advice of Skanska's soft estates specialist.

During establishment, the embankment became infested with nettles due to rhizomes and seeds contained in the subsoil. To tackle this, nettles had to be removed by hand as spraying with herbicide could have killed the wildflowers. This practical issue emphasises the importance of planting at the correct time to maximise chances of success.

Ecosystem Services

Baseline and post-construction biodiversity unit calculation was undertaken based on the metric tool issued by Defra in 2012. Baseline data were based on the known area of site clearance, and assumed all vegetation was being cleared. Post-construction calculations were based on site visits and design drawings (where planting was not yet complete). Prior to the intervention more than 75% of the site was hardstanding. The area had low biodiversity and limited functionality as green corridors. Following the works, enhanced areas were classified as 'neutral grassland – semi-improved (lowland meadows)'. The entire project (including the green walls in AP-U2) was externally verified to have more than doubled the amount of preconstruction biodiversity units, leading to a net positive increase in net biodiversity of 113%.

Social value

No quantitative data are available for amenity value. The increased greening of the area and biodiversity may provide enhanced aesthetic/visual value and in-turn may positively influence nature recreation and leisure values.

Who can apply this intervention / technique?

Any works involving replacement or modification of existing low-value or contaminated land can consider opportunities for creating improved areas for wildlife.

The 'hydroseeding' approach offers a way of encouraging valuable grassland over a large area relatively simply, on any pre-prepared ground, which can include sloping embankments where soils are relatively poor and/or thin. Where this approach is used over conventional grassed embankments, maintenance costs can also be reduced (see the Mowing bundle for details on cost savings).

Scaling up the benefits

Railway assets are extremely common, and many provide limited environmental value. Application of enhancements such as planting wildflowers on earthed embankments (greening of railway walls, AP-U2) could be widely used to improve amenity, wildlife and reduce maintenance costs compared to business as usual mown grass embankments (see CS-M1 and AP-M2). These kinds of local interventions can have broader significance by improving connectively between isolated habitat patches and enhancing the visual appeal of the wider environment, especially in heavily urbanised areas. This measure can also be used in combination with other urban IGGI measures (e.g. by adding bee habitat on the concrete elements (AP-U3-4) of adjacent railway infrastructure or CityTrees (AP-U7) to absorb pollutants at stations) to further improve the ecosystem services which IGGI can provide.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
COST		●					
ENGINEERING			●			●	
ECOSYSTEM SERVICES			●				●

Further information / Contacts

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URL: https://www.landscapeinstitute.org/news/bermondsey-dive-under/

Contacts:

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conor.mccone@skanska.co.uk

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Case Study CS-U3:

Green screen guard rail

Summary

Installation of pre-grown plants, hand-wound on Mobilane.co.uk mesh panels, in biodegradable pots and growing medium. In this case study they are attached to pre-installed rails beside a busy city centre dual carriageway in central Birmingham, providing an instant green screen to improve the aesthetic of the area and provide some air pollution reduction. The same techniques can also be used in residential and industrial areas on a range of support structures, including purpose built options, with this supplier offering a choice of around a dozen different plant species and screens in a number of sizes.

Benefit	Medium
Engineering	Medium
Ecosystem	High
Direct Costs	Slightly more

How does it work?

Varieties of ivy, hornbeam, beech, privet and firethorn are pregrown in biodegradable pots and fertile growing media, and attached to fine mesh carbon steel frames. Attached to a wide variety of supports in any setting they provide an instant greening. They provide a relatively large surface area to footprint ratio, offering opportunities for increasing habitat provision, improving biodiversity, and a mechanism for air pollution control in dense, grey urban areas where space for conventional GI is limited.

Motivation

Air quality in urban areas is a known issue for health and quality of life. Motorised vehicles produce a range of pollutants that can affect human health. These include very small particles emitted from exhaust (especially from diesel-fuelled vehicles), and from wear-and-tear on brakes and tyres. If inhaled these particles can cause a range of both short-term and more chronic health problems, including increased chances of death from respiratory and cardiovascular disease. This Particulate Matter (PM) is measured in microns (one micron is one millionth of a metre). Health concerns start with particulates of 10 microns (PM_{10}) in diameter or finer, where the smaller the size (e.g. $PM_{2.5}$), the greater the health risk.
Some plants can provide amelioration to some of these effects by capturing PMs but little is known about how this can best be exploited for practical application. The Constructor was looking for a site to conduct some research on this topic and recruited support from a local University and business development group

Design Innovation / Enhancement measure

Free-standing urban vegetation units that allow the pre-grown plants to be added to dense urban settings. A wide range of existing urban infrastructure is suitable for these kinds of measures including chain link fences, guardrails, masonry walls (AP-H1) or wooden fences.

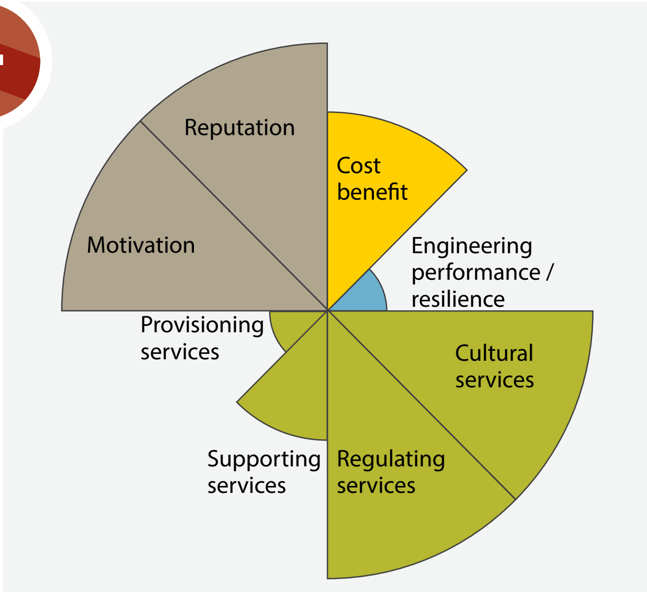
Installed and established screens of ivy

Photo Credit: Chris Rance

Photo Credit: Chris Rance

Benefits

Analysis of the leaves of the screen compared to those from a control site shows the capacity to remove pollutants. This could provide major benefits by reducing local exposure to airborne particulates linked to acute and chronic health issues, at relatively low cost. Vegetation also improves the aesthetic of heavily urbanised areas. Alongside monitoring of impacts on local pollution, this installation was partly an attempt was improve the aesthetic of the area and the economic prosperity of the local businesses. Ivy can be important for biodiversity as a source of cover for birds and, where allowed to flower, provides a valuable nectar source in urban areas for pollinating insects, and berries for birds in winter.



Net Cost

£25,000 in total for over 200 m² of screening (a 141 m x 1.3 m section and a 37 m x 1.8 m section). It may be assumed that fitting the screen on a new-build may be cheaper as the growing medium at the bottom of the guardrail can be incorporated into the build more easily than retrofitted, though this has not been tested.

Direct cost of intervention

For this scheme the IGGI measure is retrofitted to existing infrastructure, the figure of £25,000 (£125 m²) represents the whole cost.

Cost compared to business-as-usual

The cost for fitting a guardrail can vary depending on the location and any health and safety requirements, traffic management, closed roads, etc. A standard powder-coated guardrail costs £75 per m² plus installation costs which will vary considerably by site and is estimated to cost £300 per m² to install them in Bristol. Adding vegetation to guardrails would thus cost 50% more per m².

Long-term cost

Inspection and maintenance of the 200 m² screen is expected to cost around £1,000 or less per year. The green screen is designed not to require additional watering.

The long-term financial (and health) costs of not addressing urban air pollution are estimated at around £20 billion per year. Certain groups in society are more at risk than others - the young, elderly, those already in ill-health and those who live and work close to pollution sources.

Engineering performance, inspection and maintenance

Two joint maintenance and inspection visits are planned per year. Further research is required to determine how the vegetation may influence the life span of the guardrail but it is not anticipated to greatly reduce it. The measure has a minimum design life of 10 years. Some maintenance to keep the vegetation trimmed may be required.

Ecosystem Services

After laboratory analysis the roadside ivy leaves showed around 4 times more PM_{10} and particles finer than $<PM_{10}$ on their surface than leaves on control plants grown in a pollution-free greenhouse. On average the ivy leaves were predicted to capture around 145 million particles per m^2 per day.

Research is continuing but as yet many of the wider ecosystem services have not been measured.

This scheme was designed to mitigate the impact of urban pollution and improve the aesthetic in an urbanised area with reported low visual aesthetic value. The green screen vegetation may also provide other services, such as supporting other organisms (insects and birds), helping to regulate microclimate (shade, evapotranspiration) and sequestering carbon.

Social value

A motivation for this scheme was to provide 'green' in a heavily urbanised area, thereby helping to improve air quality for human health, enhance the aesthetic appeal of the streetscape and encourage business growth. In some instances, and where required, use of thorny species (e.g. Pyracantha) could be used to secure boundaries.

Who can apply this intervention / technique?

Urbanised areas provide a wealth of opportunity to install free-standing greenery. Any land asset manager could consider these for increasing biodiversity, aesthetic appeal and improving air quality. This may be especially relevant in tackling potential impacts of particulate pollution, for the wider population and vulnerable groups (e.g. boundaries of school playgrounds in traffic congested streets, CS-U3).

Scaling up the benefits

Pedestrian guardrails have been very widely used across the UK road network. Not all would be suitable for incorporat¬ing this technique, but there is widespread potential to apply this across the UK. The example here illustrates retrofitting to existing rail boundaries; for new build projects it is conceivable that a built-in solution may be possible that negates the need to combine the two elements of a green screen with support and a guardrail, fencing or wall. Combining the greening into the support during the design phase would likely reduce the costs of installation. Similarly, where crash protection function is not required, the screens can be installed with post supports without guardrails.

Data Quality

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part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
COST				●			
ENGINEERING					●		
ECOSYSTEM SERVICES			●		●	●	

Further information / Contacts

Bristol Neighbourhood Partnership Traffic Choices: https://www.trafficchoices.co.uk/traffic-schemes/guardrails.shtml

Dover, J. (2015). Green Infrastructure: Incorporating Plants and Enhancing Biodiversity in Buildings and Urban Environments. Routledge.

Staffordshire University’s Green Wall Centre: http://www.staffs.ac.uk/research/greenwall/

World Health Organisation (2016). Urban Green Spaces and Health - a review of evidence. WHO Regional Office for Europe, Copenhagen 80pp.

Contacts

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John Dover: J.W.Dover@staffs.ac.uk

Case Study CS-U4:

Green screen school

Summary

Screens of juvenile ivy plants were fitted to existing school playground fencing to block out traffic-generated pollution in London. The fumes and minute particles from exhaust and tyre and brake degradation, as well as from natural sources, can be very harmful especially for vulnerable groups.

Benefit	Medium
Engineering	Low
Ecosystem	Medium
Direct Costs	Medium

How does it work?

Where vulnerable people are in close proximity to busy roads, greening measures have been tested to play an important part in reducing local concentrations of harmful and unpleasant pollutants. A trial was conducted at St. Cuthbert with St. Mathias Primary School near to A3220 in central London. Air quality was measured directly on either side of a 51m long green screen 2.7m high that bordered the road and playground. The existing playground fencing was retrofitted with growing medium, additional support structures and ivy plants. Once the plants covered the screens, the levels of harmful nitrogen gases (NOx) and minute particles called PM_{10}, were measured on either side of the screen. Comparison data were also recorded at two other sites in the area, one away from traffic and the other kerbside with no vegetation. The mature screens were shown to significantly reduce the levels of harmful pollution on the playground side of the screen by 24% for NO_2 and 38% for PM_{10} daily (daily mean), respectively. They were most effective when the screen is dense and when traffic pollution levels were at their highest.

Motivation

The impact of pollutants on lung development and other chronic health issues is becoming better understood, and is now considered to be a serious and widespread problem. Research suggests that green barriers can reduce the human impact of road-generated pollution by acting as a pollution sink, trapping and retaining harmful gases and particulates. In addition, they can slow down the rate, and /or reduce the quantity and distance pollutants travel, thereby protecting vulnerable populations.

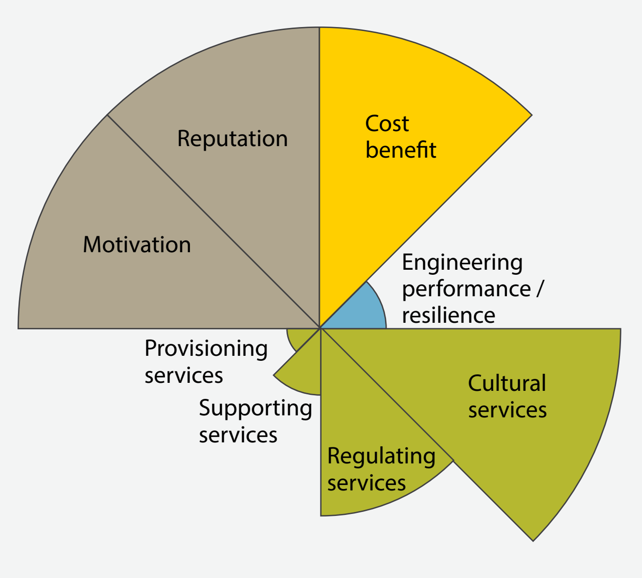
Design Innovation / Enhancement measure

Using green infrastructure to provide cost effective reductions in pollution levels in an urban primary school playground.

Benefits

The impacts of traffic generated pollution on vulnerable populations, including children, can be chronic and life shortening. The research done here and elsewhere (e.g. Weerakkody et al., in press) illustrates the potential for green infrastructure to produce significant improvements in air quality in a relatively short time-frame (< 1 year) at a relatively low cost, particularly when compared to other options such as legislative measures to reduce traffic or technological changes/alternative fuels.
More generally, green screens can be aesthetically pleasing, provide learning opportunities and create habitats for wildlife, particularly foraging for pollinators, whose numbers have been in steep decline nationally. Ivy species flower in abundance late in the season and can be an important food source for honeybees (Garbuzov & Ratnieks 2014). These potential biodiversity benefits were not measured by this study, and as such are not included in the benefits wheel.

A concern for this case study was the potential for the screen to reduce the dispersal of exhaust gases from the school's own boiler, essentially trapping the exhaust gases in the playground. Although this was found not to be an issue here, it is worth noting that there is a potential risk in some situations; where the screens sufficiently reduce airflow and are in close proximity to emission sources.



Net Cost

No data on net cost were available.

Direct cost of intervention

No figures were available for the installation or maintenance costs of this specific scheme, where watering was required help establish screen plants. An approximate figure for supply and installation of green screens is £125 per square metre (as at 2015, see CS-U3) although this could vary regionally and according to the specifics of the site, supplier and fitter.

Cost compared to business-as-usual

These screens were retrofitted to pre-installed fencing, raising the height by 0.7m. For new build scheme, purpose made green screens are available (see CS-U3). The increased cost for these can be relatively large, sometime more than double the lowest priced alternative, although reduced vulnerability to air pollutants may equalise the cost in the longer term, depending on location.
In addition, in areas of high pollution and a high concentration of vulnerable people the additional expense could be justified as a measure to improve health and reduce exposure to toxins.

Long-term cost

Increased concentration of traffic-generated pollution can slow the development of children's lungs. As a tool to minimise this, these green screens produce significant improvements in air quality in a localised high risk area in a relatively short time-frame (months) at a relatively low cost. This is an alternative to restricting access to the playground and can help reduce risk to vulnerable groups whilst legislative and technological changes to reduce air pollution take effect. The long-term value would appear to be high and the cost relatively low.

Engineering performance, inspection and maintenance

No data is available on the performance of the screen as opposed to a traditional link fence or other traditional design. The extra loading could be problematic in some areas in high wind conditions, increasing the need for repairs from storm damage and particularly vigorous growth could make inspection more time consuming (where inspection occurs on chain link fencing), although the screens are designed to require no maintenance once installed and established (and watering is no longer required).

Ecosystem Services

The green screens were highly successful at providing improved regulatory services, in the form of improved air quality in a few months post-installation. Although not their intended primary function, the screens may also provide some additional ecosystem services, beyond the regulatory service of improving air quality. These were not measured by this study but could, for example, include creating shade and helping to reduce heat island effects, reducing the effect of high winds and attenuating rainfall, sequestering some carbon and contributing to the cycling of nutrients.

No data is available on the other wildlife-related ecosystem services benefits of this case study but other work shows the screens can provide habitat important for wildlife, particularly pollinators, but also other insects and birds (Chilquet, 2014). The location of screens installed to address high levels of pollution could be significant in that they will be providing habitat in highly urbanised areas and may function as connecting habitats and/or by creating stepping-stones between habitats.

Social value

The green screens were highly effective at providing a quick, inexpensive way to reduce the significant health impact of air pollution, at a local scale (e.g. one school playground). This was of high value locally and if applied widely could have substantive social value to society.

Who can apply this intervention / technique?

Ivy are relatively hardy, fast growing plants that require little attention or maintenance when correctly installed (see CS-U3 for details). Similarly the screen supports do not require frequent or specialist maintenance unless positioned in front of free-standing masonry walls or buildings (see AP-H3 and AP-H4 for suggested maintenance and asset resilience benefits of ivy). Where pollutants like those generated by traffic could negatively impact on people's health and wellbeing, or where greening is needed in dense urban areas where other GI options are not available, the green screens (see also CS-U3) and other IGGI measures (e.g. see AP-U6, AP-H4) that use plants that trap or slow down the transport of pollutants could be applied.

Scaling up the benefits

The screens and similar greening innovations, along with more traditional green infrastructure like urban trees in parks and greening of buildings (see London Ecology Masterplan in the main report) can collectively provide long term, cost effective benefits in a huge number of urban spaces, at local (e.g green screens for schools) to strategic scales (e.g. urban forests and ecologically focused masterplans). There is a growing acknowledgment of the health benefits of urban green infrastructure, and while these results and similar studies suggest the potential benefits of green screens are great, it is important to acknowledge that placement is key in maximising the benefits. In many instances these screen can form part of a combination of measures that can address a range of issues that impact on the resilience of urban areas, particularly in light of predicted climate changes.

It is also important to better understand the spatial scale of the air pollution benefits and other ecosystem services that green screens provide, so that we can more precisely measure the specific benefits associated with implementing this IGGI measure. This would improve the benefit and cost assessments provided above and in CS-U3.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
COST		●		●			
ENGINEERING							
ECOSYSTEM SERVICES			●	●		●	

Further information / Contacts

Tremper, A.H., Green, D.C., Chatter-Singh, D. and Eleftheriou-Vaus, K. (2015). Impact of green screens on concentrations of particulate matter and oxides of nitrogen in near road environments. Environmental Research Group. King's College London. Prepared for the Royal Borough of Kensington and Chelsea.
URL: https://www.rbkc.gov.uk/environment/air-quality/air-quality-projects

Garbuzov M. & Ratnieks F.L.W. (2014) Ivy: an underappreciated key resource to flower-visiting insects in autumn. Insect Conservation and Diversity, 7, 91–102.

Weerakkody, U., Dover, J.W., Mitchell, P., Reiling, K. In press. Particulate Matter pollution capture by leaves of seventeen living wall species with special reference to rail-traffic at a metropolitan station. Urban Forestry and Urban Greening
URL: http://dx.doi.org/10.1016/j.ufug.2017.07.005

Contacts

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Urban Art of the Possible

Art of the Possible

Green Tram

URBAN

AP-U1

What is the measure?

Replacement of traditional tram track beds with green solutions designed to improve amenity, wildlife, pollutant trapping and water infiltration. Green (or grass) tram beds have been used in parts of Germany for over 25 years, used as part of the standard design in aesthetically sensitive areas. In this example, the green track was designed to mimic ecologically diverse low nutrient meadow habitat that provides more ecosystem services for lower cost than grass tram tracks.

Primary driver

Green tracks are used to provide a wider range of benefits to people and wildlife than traditional grey tracks can provide in aesthetically sensitive areas of cities. This specific example demonstrates that green tracks can be better designed to improve ecological outcomes, whilst maintaining their amenity value for society.

Benefit

All types of green tracks provide improved ecosystem services compared to traditional grey tracks such as water attenuation, pollutant trapping, improved amenity or habitat for wildlife. For low nutrient meadow tracks compared to more typical green grass tram tracks, the ecological benefits are improved and cultural ecosystem services are maintained. The dry low nutrient meadow habitat requires less maintenance than grass tram tracks, and it is more resilient to dry periods than grass, making it well-suited for a drier future climate.

Cost

Construction costs for green track systems compared to traditional grey engineering options are difficult to generalize but may cost up to 1.5 to 2 times more than grey track options. Construction costs for low nutrient meadows are the same as for grass tram tracks, and maintenance costs are reduced compared to grass tram tracks due to reduced mowing costs. Green track beds have been piloted in Edinburgh, Manchester and Birmingham, however, no data were available.

Engineering

Green track systems can be designed as high or low level systems; high track systems require different construction (rails are insulated) but less maintenance than low track systems where more mowing is required. For low nutrient meadows there is no difference in construction compared to green tracks. Maintenance of the low nutrient, meadows is much less than the mowing required for grass tram tracks, providing maintenance cost savings with no adverse impacts on engineering performance or design life of the tracks.

Ecosystem services

The low nutrient, meadow provides habitat for a greater range of species than either traditional grey or grass tram tracks provide whilst providing similar aesthetic value for society. They provide linear corridor habitats that support key pollinators (bees) and ground beetles. Green tram systems can be tailored to different climates and funding availability, as demonstrated by the wide array of approaches across Germany.

Social

From a social perspective, use of green tracks is of great importance and local residents are more likely to provide consent to build new tracks where the green track construction method is proposed.

Reputation

The low nutrient meadow scheme was awarded the 2017 State of Baden-Württemberg's Innovation Prize for public transport for "Ecology in local traffic".

Policy

Where tracks are segregated from roads, it is typical to build a type green track system instead of grey track beds in urban areas.

Further data

Kappis, C, Scheiter, H, (2016). Handbook Track Greening - Design, Implementation, Maintenance. Eurailpress, DV V Media Group, ISBN: 978-3-87154-576-4

Contacts:

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Art of the Possible

Green railway walls

URBAN

AP-U2

What is the measure?

To improve conditions for wildlife as part of a Thameslink programme to increase railway capacity, invasive and woody vegetation was removed and poor condition, low biodiversity hard assets were replaced with green walls (the focus here) and wildflower embankments (CS-U4). In total, 765 m^2 of green walls were installed in locations that would otherwise be void space under arches and access ramps. Geotextile membranes were added to the sides of structurally strengthened railway infrastructure and hydroseeding was used to plant species of low maintenance and high wildlife value.

Primary driver

Redevelopment of a network rail site to improve capacity for rail users required onsite mitigation for the habitat affected by the works; these greening works sought to improve conditions for wildlife on site.

Benefit

Invasive vegetation and contaminated soils were removed from the site and green corridors were added to new structurally strengthened railway assets to mitigate for habitat losses created by the works. This measure, combined with the earth embankment wildflower planting and altered mowing regime, has lead to a net positive increase in biodiversity of 113% or more than double the amount of preconstruction biodiversity units.

Cost

The geotextile membrane wrapped retaining wall cost approximately £220/m^3 compared with £600 m^3 for a reinforced concrete retaining wall. The total construction cost (2012 prices) fro 765 m^3 was 54% cheaper (£380K compared to £800K) for 765 m^3 of walls. Inclusion of the green walls increased the habitat provided by 14%; to out perform the net positive target by increasing biodiversity on site by 113%, which is less expensive than offsite mitigation.

Engineering

Use of green walls has had no adverse effect on the engineering performance of the asset after 2 years – as the wall is not a structural element of the bridge it is not envisaged this will be an issue. Higher maintenance costs are expected in the long-term compared with a business-as-usual reinforced concrete retaining structure – however, construction costs are less than ½ of the traditional grey engineering option.

During establishment, the green walls became infested with Buddleia due to poorly timed planting (leaving the surfaces exposed to dispersing seeds before cover was established). This meant that the green walls had to be stripped and resprayed (costing an extra £10K) in autumn to give the seed a better chance of achieving good coverage. This practical issue emphasises the importance of planting at the correct time to maximise chances of success, and reduce construction costs.

Ecosystem services

No data on supporting or provisioning ecosystem services were collected here, but other studies have compared meadow flower mixes compared to grass and have found significant ecological benefits from the flower meadows. Together with the wildflower planting, these two measures led to a 113% net positive increase in biodiversity compared to the 75% hard standing (grey) assets the ecological enhancements for the scheme replaced.

Social

No social data were gathered.

Reputation

This project was shortlisted for a CIRIA biodiversity challenge award (2017)
The project achieved 96.6% in the CEEQUAL Whole Team Award
Winner of the Ground Engineering Sustainability Award (2017)
Winner of the ICE Infrastructure Award (2017)

Policy

Thameslink Programme's (TLP) Sustainable Development Policy aims to achieve an overall net positive biodiversity = Ecological Net Gain.

Further data

URL: https://www.landscapeinstitute.org/news/bermondsey-dive-under/

Contact:

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Bee walls

What is the measure?
Community engagement activities took place to create combined bee habitat on, and around, an existing breeze-block bin store. The measure is linked to small-scale herbaceous habitat creation on neighbouring green spaces.

Primary driver
A local Housing Association in Dorset had a requirement to support community development and engagement; to support the local community in improving their local environment.

Benefit
Anticipated benefits:

- Reduced maintenance – grass cutting (replaced by mixed herbaceous planting).
- Reduced vandalism through self-monitoring – greater community use and sense of ownership of the space.
- Housing Association perceived more positively – improved key performance indicators (KPI's).

Cost
Costs were covered from existing Housing Association budget.

Engineering
The breeze-block wall was not compromised, rather it is thought the design life will be improved by the additional rendering required to create the bee nesting habitat.

Ecosystem services
Created habitats for wildlife including nesting habitat for invertebrates in a breeze-block wall and on a mini-dune sand bank, and foraging opportunities from herbaceous planting. Also created interactive amenity play spaces. The rendering of the wall incorporated habitat for breeding, overwintering and basking invertebrates, particularly the pollinators *Osmia bicornis* (Red Mason Bee) and *Anthophora plumipes* (the Hairy-footed Flower Bee). The herbaceous planting included bee foraging species and colourful, edible plants attractive to other species. Future monitoring of the scheme is planned.

Social
The design, creation and installation of the habitats was undertaken with the involvement of the community, in part through the Housing Association's requirement as a social landlord. The new planting connected the area around the bee wall with the adjacent riparian parkland, creating gateways in and out, transforming the wall from a utilitarian structure with little or no aesthetic value to a new social focal point.

Reputation
The Housing Association have commissioned additional projects that similarly link planted and built interventions for wildlife, wildlife encounter and enriched common spaces. The supplier feels the Housing Association have "an increased awareness of the potential socio-economic benefits of this business model". Housing Association perceived more positively by users – improved KPI's.

Policy
The suppliers feel the Housing Association have incorporated many of the ideas of this scheme, i.e. "bioactive planting linked to bioactive buildings" and that it has become influential in the way new developments, maintenance programmes and resident 'involvement' initiatives are planned.

Further data
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ian@artecology.design, http://www.artecology.space/

Art of the Possible

Bee bricks

URBAN

AP-U4

What is the measure?

Bee bricks are building bricks that are designed to provide habitat for solitary mason and leaf cutting bees. This product is commercially available and was tested at 128 sites in Cornwall.

Primary driver

Traditional bricks in freestanding walls and houses provide little or no ecosystem services. Solitary bees are vital pollinators that do not disturb or harm people. A brick designed to improve solitary bee habitat was tested to see if novel bricks can improve bee habitat.

Benefit

Bee populations on walls were improved through installation of bricks even during a wet cool spring of 2016 when the study was carried out. This improves the amount of habitat and number of pollinators vital to our food supply. The bricks are made using waste aggregate, which also reduces their carbon footprint.

Cost

The bricks retail for £27.50 each (with tiered bulk discounts available up to >75 bricks at £14 each); this compares to ~£1 - £10 for conventional bricks, making the bee bricks between 2.75 – 27.5 times more expensive per unit (or 1.4 – 14 times for bulk buy). Bulk purchasing of bricks would improve the cost ratio compared to traditional bricks, and it is important to note that ecological benefits can be gained from as little as 1 brick per m^2. Adding 10 bricks to a 100 m long retaining wall would thus add a maximum of £275 to the cost.

Engineering

The bricks are non-load bearing and have been designed to not impact on building quality or engineering performance of free-standing walls, and require no maintenance for many years. They need to be used at least 1 m above ground, with no upward limit, and on non-shaded, south/south easterly facing walls for ecological reasons.

Ecosystem services

Supporting and provisioning ecosystem services were measured in this study where 34% of bee bricks had nesting bees during the course of the 5 month study carried out by the University of Exeter. Bee density in bricks was correlated with the presence of bees in the surrounding area, where low bee numbers in bricks was consistent with low populations in the surrounding gardens surveyed. Greater bee densities were found foraging on native compared to non-native flowering plants.

Reputation

Awarded the Soil Association Innovation award and winner of 'Best innovation' at the Cornwall Sustainability awards. The Duchy of Cornwall have included bee bricks in their new town in Cornwall, to help showcase how the built environment can also provide ecosystem services.

Policy

There is local supplementary planning guidance in Cornwall that stipulates bee bricks must be incorporated into 50% of new homes.

Further data

Contacts:
Faye Clifton: faye@greenandblue.co.uk, @GreenandBlueUK

URL: https://greenandblue.co.uk/product/bee-brick/

Bee benches

What is the measure?

Two biophilic public benches in a developing community greenspace. The benches were designed to provide habitat for bees and nectar-providing plants.

Primary Driver

Former arable land under agri-environment scheme to create new woodland with permissive public access, strong links to parish council and environmental collaboration with village primary school. Ecological surveys revealed exceptional bee assemblages leading to a need for public information and positive engagement.

Benefit

Bee species were recorded nesting in the benches within 12 months of construction. Strong focus of conservation interest and recreational space for people of all ages from the design and construction (with a school) to long-term use by increasing numbers of visitors, at very low installation cost and zero maintenance since 2012.

Cost

£2k per bench, including educational engagement and workshop session. Design and installation responds to site, containing bespoke features sympathetic to the local ecology. This costs between £1k and £2K per bench inclusive of outreach and installation. In comparison, a traditional, treated wood park-bench for park or amenity use costs between £660 and £1150 inclusive of installation but with no public engagement provision or ecological value.

Engineering

'Anthropic stone' concrete mix was used to sculpt benches over armature of recycled materials.
Field sand used in the mix for colour and substrate compatibility. The benches have required no maintenance in the five years since installation. The techniques and materials used provided important lessons for subsequent ecologically-favourable concrete work.

Ecosystem services

The benches were constructed to include small internal chambers, 'micro-planters' for field floras to colonise and a complex sculpted surface incorporating nest holes for species such as mason bees.

The project delivers a high density of wildlife activity in an area where people were more likely to encounter it, a form of 'urban rewilding'. The benches in their first season supported breeding mason and bumble bees, with associated commensals and parasites. Care was taken to put neither wildlife nor people at risk; this was managed through design and public information.

Social

The bee benches provide a landmark for visitors. They have become a public showcase for IGGI and for biologically favourable built environments. The local primary school regularly uses the site for environmental education; the benches and the space around them are designed to facilitate outdoor lessons. The school subsequently commissioned a nursery play area in the same materials and with a bee theme.

The benches exemplify handmade sculptural habitats that combine decorative function with ecological improvements, encouraging wildlife encounters. Pollinators provide a useful focus for public engagement but designs can also target other 'small wildlife' species (invertebrates, small mammals, reptiles, amphibians).

Reputation

The project helped bring public and specialist attention to the site and led to the landowner gifting the site to the county wildlife trust. The bee benches, and the 'bee fields' brand they have generated, have built important ties between the landowner, the village and the parish, prompting the consideration of other opportunities for local collaboration around land management for conservation and public benefit.

Policy

IGGI as a technique for hard/soft landscape 'merging', as developed by Artecology here, has become better understood locally and therefore more likely to be considered as an option in design and build projects. Those organisations involved in the project have become more aware of how bespoke alternatives to traditional construction methods can be usefully tailored to local environmental conditions.

Further data

Ian Boyd, Artecology:
ian@artecology.design, http://www.artecology.space/
URLs:
www2.eastriding.gov.uk/living/deaths/memorial-benches/
www.londongardenstrust.org/features/bench.htm

Art of the Possible

Trees for health

URBAN

AP-U6

What is the measure?

The aim was to create an attractive front close to a high profile health resource in a highly deprived area that contributes to a wider green network linking other resident to this and other local NHS facilities. This street tree installation was designed to provide improved air quality outside and unusually, also inside the building. It also serves to help cool, screen and improve the amenity from inside the building.

Primary driver

Air quality, privacy and views into waiting areas of the health centre were raised as an operational issue as the glass fronted building is on a heavily trafficked street. Tree planting was thought to be beneficial in addressing this, and softening the hard engineered and traffic dominated street frontage through greening. The building design left too little space for tree planting using traditional techniques so a novel design of tree planting close to buildings that aimed to improve air quality, amenity and privacy for NHS patients and staff.

Benefit

The tree planting at Possil Park Health Centre was realised as part of a wider package of public realm works funded jointly by NHS Greater Glasgow and Clyde and the Green Exercise Partnership (a partnership between FCS, SNH and the NHS), and it has multiple ecosystem service benefits for society and nature including improved amenity, air quality and surface water management.

Cost

No cost data are available.

Engineering

As this was essentially a 'retrofit' solution, the trees had to be located relative to existing and recently installed services in the footway. This determined the positioning of the trees and care was required to locate services, excavate and install the trees with root barriers to minimise the impacts of roots on services and the building edge. If these were designed into future schemes, co-designing services and greening would improve construction efficiency and cost.

Ecosystem services

Benefits are realised in terms of regulating services such as capturing particulate pollution, surface water management benefits through permeable surfacing over the tree root zone and supporting services via some habitat creation in the streetscape. They also were designed to control heat inside the building, providing a regulatory service. No data on the actual benefits of these ecosystem services were collected.

Social

Benefits are realised in terms of regulating services such as capturing particulate pollution, surface water management benefits through permeable surfacing over the tree root zone and supporting services via some habitat creation in the streetscape. They also were designed to control heat inside the building, providing a regulatory service. No data on the actual benefits of these ecosystem services were collected.

Reputation

The tree planting forms part of a Greening the NHS Estate (Scotland) initiative which aims to improve wellbeing through improved access to greenspace and to use greening to help regulate air and thermal properties inside buildings.

Policy

The tree planting was delivered as part of a demonstration project instigated by the Green Exercise Partnership to demonstrate the value and importance of making the NHS estate usable and accessible to patients, staff and the wider community.

Further data

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Anne Lumb, Green Exercise for Health Partnership, NHS Scotland.

URLS: http://scotland.forestry.gov.uk/news/1214-greening-possilpark
http://www.nhsggc.org.uk/about-us/media-centre/news/2015/4/possilpark-health-and-care-centre-officially-opened/

Art of the Possible

CityTree

URBAN

AP-U7

What is the measure?

Green elements are added urban street furniture where the natural processes the plants and mosses can cool air temperature and provide reduce gas and particulate air pollution, and in localised areas, at street level. They reduce carbon dioxide (CO_2) by an estimated 240 t/year. As a novel technology, the CityTree has had limited testing to date and it being trialled in Jena, Germany and Glasgow, Scotland.

Primary driver

Air pollution is a major public health and environmental issue in large cities worldwide. There is a need to help improve air quality with practical measures alongside policy changes to reduce pollutant loads over time.

Benefit

Poor air quality is directly correlated to poor human health. CityTrees provide a concentrated pollution reduction system, locally moderate high temperatues and provide a focal point to increase awareness of urban air quality through educational material on the CityTree structure. Correctly installed, these and similar urban greening innovations, can be important elements in a strategic programme to manage urban air pollution. The CityTree example provides high profile low maintenance options that can be included in a suite of measures to address a widespread problem.

Cost

An initial cost of around £22k per freestanding unit, delivered and installed. Alternative more traditional urban greening opportunities are well established – trees, hedges and IGGI measures including green screens (see green screen case studies CS-U3 and CS-U4). Although the CityTree may optimally process a greater volume of pollutants, it does not cover as large an area or provide the additional benefits of shade, rainwater interception, wildlife value and improved well-being and amenity that urban trees have been shown to provide (AP-U6).

Engineering

It is a freestanding 4 x 3 m unit comprised of a built in bench, moss screen and information board that once built are carbon neutral to run. The screen is a self-sufficient, standalone structure which requires minimal annual maintenance (a few hours per year). Rainwater is harvested for irrigating the vertical moss screen and a solar panel generates electricity to power the pump and air quality monitoring station. Each unit contains smart sensors that collect environmental and climate data to help regulate and control to for the moss cultures, and provide live data on air quality.

Ecosystem services

The CityTree is designed to provide regulatory and cultural ecosystem services. No data were available to quantify the amount of air pollution absorbed by CityTree, but monitoring is on-going. The CityTree has been found to locally reduce air temperature (by up to 10 degrees Celsius). The units can complement other IGGI measures like Trees for Health (AP-U6) and Green screens (CS-U3 and CS-U4) which can be used in dense urban areas.

Social value

As large and distinct pieces of street furniture with the capacity to provide digital interactive experiences and live air quality data they provide opportunities for public engagement, awareness raising and education on related health, wellbeing, and environmental issues of urbanisation.

Reputation

The Glasgow trial of the CityTree is being carried out as part of wider city-wide initiatives to improve air quality and adapt to climate change.

Further data

Green city solutions.
https://greencitysolutions.de/en/contact/

Sanger, P., Splittgerber, V. (2016). The CityTree: A Vertical Plant Filter for Enhanced Temperature Management, 75- pp. In Leal Filho, W. (ed.), Innovation in Climate Change Adaptation, Climate Change Management, Springer. DOI 10.1007/978-3-319-25814-0_6

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Art of the Possible (Bite-size)

These examples present IGGI innovations that have little or no data, where suggestions of what the benefits might be are made.

Car park rain garden

A small rain garden located within a car park in Edinburgh, Scotland. The plants and permeable ground allow for infiltration, thus reducing flood risk.

Roadside planting

A small area of green planting at the roadside close to the University of Glasgow, Scotland. The plants will help to intercept and trap pollutants and also improve the aesthetic value of the area.

Linear orchard

A narrow linear orchard (< 2 m wide) planted at the back of a car park that provides an edible and educational resource for a local social enterprise community centre in a deprived area of Glasgow. It also provides a visual barrier between the car park and a light industrial estate.

Industrial estate planting

A small area of green planting in an industrial estate in Liverpool, England. The plants will help to intercept and trap pollutants and also improve the aesthetic value of the area.

Inner city greened benches

Several small areas of green planting with benches attached as part of the design in London, England. As well as trapping pollution and reducing runoff into sewer systems these areas provide a public amenity.

Sunken rain garden

A sunken rain garden beside a large building in London, UK. As well as improving the visual aesthetic of the area, this rain garden will greatly reduce runoff into sewer systems.

Green pillars

Some greened pillars in London, England. Over time the vegetation will expand to form a canopy thus improving the visual aesthetic of the area and increases pollutant capture.

Living wall London

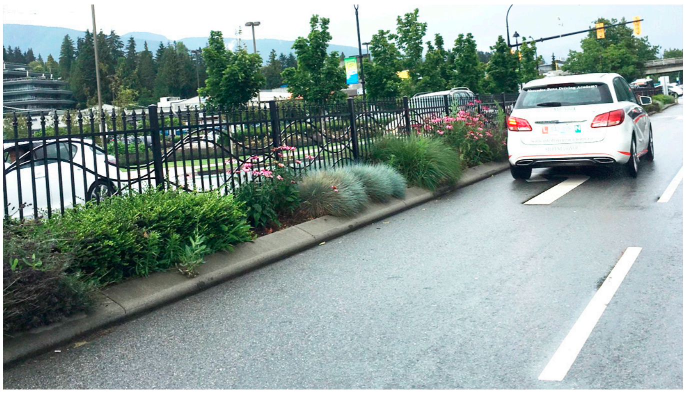
A living wall made up of many different species of plant in London Heathrow, England. This wall will control humidity and reduce ambient noise as well as serving to increase the visual aesthetic of the room and thus improve associated mental health.

Tottenham floating reed beds
The installation of floating reed beds as part of the Love the Lea project in Tottenham, England; they were funded by HSBC's corporate social responsibility initiative. The beds will help to improve water quality and bring the river into line with WFD objectives

Lea greened embankment
A greened embankment of the River Lea in Tottenham, England. As part of the Love the Lea project, this embankment will help to intercept pollutants entering the river and improve water quality.

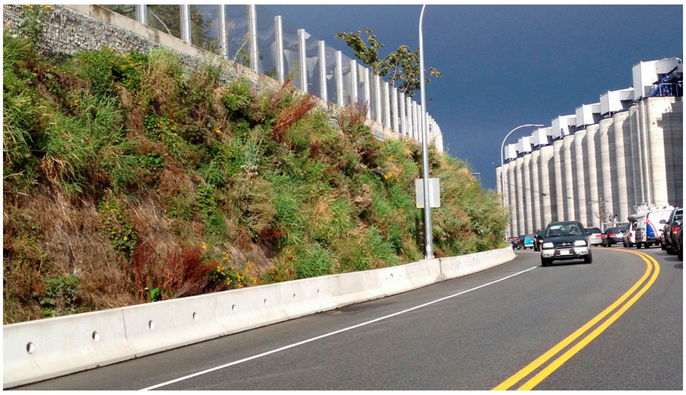
Manchester green street divider
A small greened area that had been used to separate the carriageway from the cycle lane in Manchester, England. As well as improving the aesthetic value of the area, the greened area will help to intercept and trap traffic pollution, thus protecting cyclists and pedestrians.

Bee planter
A small planter filled with various types of vegetation in North Berwick, Scotland. The main function of this planter is to provide sources of nectar for bees in order to increase local populations.



Green traffic island

A greened area in the centre of the road in Vancouver, Canada. As well as improving the aesthetic value of the area, the greened area will help to intercept and trap traffic pollution.



Green road embankment

A green road embankment in Vancouver, Canada. As well as improving the aesthetic value of the area, the greened area will help to stabilise the soil preventing any material being washed onto the road surface as well as intercept and trap traffic pollution.

Green pedestrian subway embankment

This image shows a green embankment above a pedestrian subway in Windsor, England. As well as improving the aesthetic value of the area, this embankment will also improve connectivity between habitats.

Green arches

Metal arches that have been added with climbing plants starting to grow up and over the road surface. This will improve amenity on Newcastle University's campus and attenuate rainfall as well as absorb pollutants when fully grown.

This forms part of Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Appendix 3: Mowing

This appendix is one of four environment topics covered as part of the NERC funded project report: Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Business Case for 'Mowing for Pollinators' as an Integrated Green Grey Infrastructure (IGGI) Measure

This business case assesses the existing evidence of integrated green grey infrastructure (IGGI) measures that can support wider implementation of 'mowing for biodiversity' activities. It forms part of the NERC funded IGGIframe project outputs (URL: http://eprints.gla.ac.uk/150672/). Costs, benefits and measures of the engineering and ecological performance (called critical success factors) of a range of IGGI alternatives to traditional 'grey' approaches are drawn from operational and research examples across the UK and beyond.

Measures considered involve changing embankment mowing regimes to improve habitat for bees (CS-M1); replacing grass on verges with wild flower meadow (AP-M1); and improving conditions for wildlife and people using urban grassland (AP-M2). The business case is aimed at reducing the uncertainties when considering GI innovations, including:

- What are they?
- Where have they been applied?
- What evidence is there to show they work well?
- Will it cost more?
- What are the benefits over business-as-usual?
- What IGGI measures and solutions are there?
- Where are they suitable?
- What are the risks?
- How can I get approval?

What is it? / Greening innovation

Change of maintenance regimes to reduce cost and improve ecosystem services without any engineering impacts. Key drivers have been to save money, to improve biodiversity and/or amenity value.

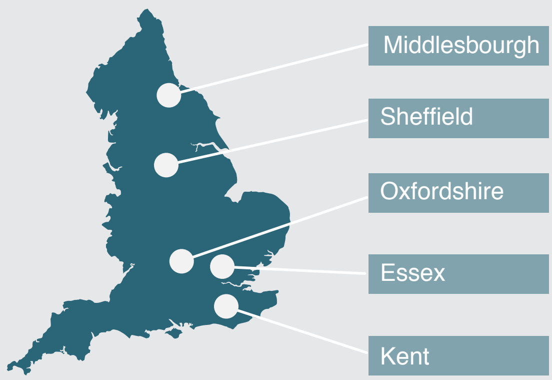
What types of infrastructure have been greened using this technique?

A range of linear and urban assets including: earth embankment flood defences, road verges, central reservations and industrial estates.

When in the design/life of an asset can this be applied?

As a strategic design goal (mowing for biodiversity) and as part of routine maintenance practice and/or as a cost saving measure. Mowing for pollinators is a cross-cutting measure that can be applied in a range of contexts. This includes any vegetated verge, bank or back/top of an existing asset that has an existing mowing regime. In this way, the measure may be used alongside other IGGI measures to achieve addition benefits in urban, coastal/estuarine and historic contexts.

Where has this innovation been tested or applied?



Evidence Summary

The evidence summary and benefits assessment are a summary of the critical success factors evaluated for all of the coastal case studies and 'Art of the Possible' examples. It is replicated across the four business cases to enable comparison between environmental contexts.

Costs

What do they cost compared to business-as-usual?

Reduced frequency of mowing gives overall reduction in costs (e.g. staff time and fuel).

LESS

Ecosystem Services

What evidence do we have that they deliver ecosystem service benefits?

Biodiversity is enhanced by providing grassland and/or wildflower meadow. This has significant benefits for pollinator species.

POSITIVE

Engineering

Are there any risks to design life, inspection or effects on maintenance regimes?

No risk to design life. Possible small changes to asset inspection (i.e. timing).

NEUTRAL

Policy

How does it relate to policy and guidance?

Can help meet national pollinator strategic objectives and/or local Biodiversity Action Plan targets for bees.

ACHIEVED

Data Quality

What is the quality of the data underpinning this bundle?

There are very good examples of this measure being implemented, including detail ecological survey data showing positive outcomes for wildlife.

MODERATE - HIGH

Social

What are the potential additional social benefits - jobs, cohesion, education etc.?

Improved amenity value, improved community cohesion (some of the schemes have involved corporate-community partnerships) and new jobs have been created (Westhorpe scheme).

POSITIVE

Reputation

How have the schemes helped improve public perceptions?

Led to improvements in corporate reputation, gained public support for changes in management and won awards (AP-M1). Local authority cuts and 'reduced' service provision has been offset by wildflower meadows that have high public approval.

POSITIVE

Asset Resilience

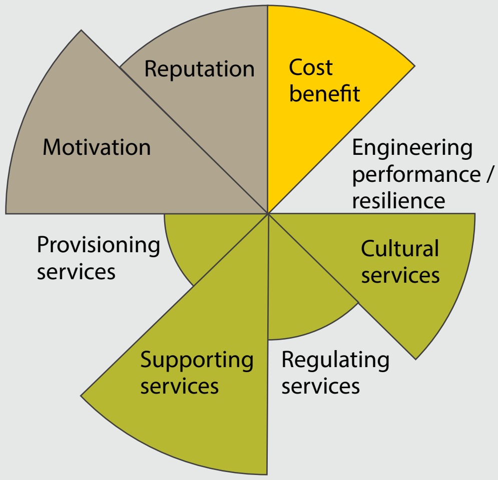
Is asset resilience affected, neutral or improved?

Changes mowing practice has little adverse effect or benefit on structural integrity of earth embankments or verges.

NEUTRAL

Benefits Assessment

The evidence summary presented above is derived from the examples contained in this bundle, each of which have been assessed using the Critical Success Factors guidance developed by this project. The benefits wheels show the benefits of each critical success factor relative to each other. They are a combination of ecosystem services and other important considerations necessary to evaluate IGGI measures compared to business as usual. More detailed breakdown of each element of each can be found below.



Cost
Reduced frequency of mowing reducing labour and fuel costs, although this is offset partly by possible increased costs of machinery maintenance due to cutting longer grass. Overall costs are considered neutral or slightly reduced compared to business-as-usual.

Engineering value
Mowing regimes have very little impact upon engineering performance. Whereas mowing frequency is reduced, grass is still cut during the year and so there is no concern with vegetation becoming unmanaged or possibly compromising engineering performance.

Cultural services
Reduced mowing supports semi-natural grassland habitats. These are rich habitats that often support wildlife of value to local communities. This includes opportunities for learning, aesthetic value, recreational and reflective experiences.

Regulating services
Grassland habitats provide some carbon sequestration.

Supporting services
Grassland habitats host valued pollinator species, important for supporting resilience ecosystems and agriculture. Examples show that reduced mowing can increases the number of native needs, including rare species.

Provisioning services
Little/no provisioning benefit is expected on-site, although may be opportunities for biomass and renewable energy production from cropped grass. Locally, the pollinators supported by longer grass and wildflowers important for commercial arable agriculture.

Motivation
IGGI measures can provide significant returns on investment and address the issues that motivated their implementation (e.g. statutory mitigation, threatened species etc.), by providing useful habitat, pubic engagement and amenity.

Policy
Reduced mowing can support protection of target pollinator species.

Reputation
Examples of reduced mowing show a mix of responses from the general public. Most appreciated the added value for wildlife, but some may perceive it as a lack of appropriate maintenance – education and engagement around the benefits can help appease these concerns.


Photo credit: Skanska

IGGI Measures

This bundle contains three IGGI measures:

Aim of the IGGI	Label	Title
Reduced maintenance /altered mowing regime to improve pollinator habitat and abundance	CS-M1	Embankment mowing for bees
Replacing grass verges on road estate land with flower meadows	AP-M1	Flower meadow verges
Improve the local environment for wildlife and people by improving biodiversity onsite and create a native tree	AP-M2	Urban grassland

IGGI solutions and relevance to other bundles

These IGGI measures can be applied more widely than the examples put forth here, as it can form part of managing of the wider more conventional green infrastructure estate including parks and open spaces.

In an urban context, these measures can be combined with enhancements to building or free-standing wall fabric (e.g. AP-U4, AP-U5) and street furniture (AP-U3) to optimise the value for people and pollinators. These measures can also complement greening techniques used on railway arches, embankments and sidings (e.g. CS-U4, AP-U1, AP-U2).

How can you get this type of greening approved for your scheme?

The case study, art of the possible examples and policy links provided here can be used to demonstrate the economic, environmental and social benefits that can be gained from this type of IGGI innovation. What is also required is a willingness to innovate where testing or application of these innovations often requires changes in behaviour or practice. For example, austerity was a key driver of innovation for AP-M1 where the need to make substantive savings to maintenance budgets for road networks and parks led to an innovative, low cost solution.

Known limitations or risks associated with these IGGI approaches

Risk Factor	Description and Risk Reduction Strategies
Ecosystem service provision	Different altered mowing and planting regimes can cater to specific species or overall biodiversity, but not necessarily both at the same time. Clear biodiversity goals need to be agreed at the outset and other forms of vegetation may also be more suitable than flower meadows.
Ecological connectivity	The potential wider benefits of improved habitat connectivity using these IGGI approaches is high; but it has not been measured by these examples so the precise benefits are currently unknown.
Geography	These can be widely applied across the rural to urban landscape. Where used in dense urban areas, it is recommended that additional habitat features are provided for key species such as solitary mason bees. Examples in the urban bundle can be used to provide these habitat alongside those in the mowing bundle to achieve this.
Machinery	Mowing late in the season may put additional pressure on equipment in terms of wear and tear (e.g. vegetation will be woodier but machines used less often) and also availability of machinery for cutting. Careful planning is needed to optimise ecological gains within operational constraints of limited numbers of mowers.
Maintenance	Although maintenance is typically less than for grass-mown features, there is still a clear need for a maintenance operational plan to be made and followed over time. Annual maintenance is critical for flood alleviation embankments to retain their engineering design performance criteria.
Scale	There is potential for widespread application of these IGGI approaches; limits are the availability of machinery for late season mowing.

Where to learn more

Case study: CS-M1 and references therein
Art of the Possibe: AP-M1 and AP-M2

HM Treasury (2016). The Green Book: Appraisal and Evaluation in Central Government. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf [Accessed August 2017].

DEFRA (2015). National pollinator strategy: for bees and other pollinators in England. https://www.gov.uk/government/publications/national-pollinator-strategy-for-bees-and-other-pollinators-in-england [Accessed August 2017].

Scottish Government (2016). Scottish Pollinator Strategy Consultation. http://www.snh.gov.uk/about-scotlands-nature/species/invertebrates/land-invertebrates/pollinator-strategy-consultation/ [Accessed August 2017].

Welsh Government (2015). Action Plan for Pollinators. http://gov.wales/topics/environmentcountryside/consmanagement/conservationbiodiversity/action-plan-for-pollinators/?lang=en [Accessed August 2017].

A related technique involves greening stalled brownfield sites using wildflowers to attract pollinators, e.g. Buglife's 'Managing brownfield sites for scarce bumblebees'. https://www.buglife.org.uk/sites/default/files/Managing%20brownfields%20for%20scarce%20bumblebees_0.pdf [Accessed August 2017].

Plantlife also has guidance on 'Good Verges' which may also be applicable: http://www.plantlife.org.uk/uk/our-work/publications/good-verge-guide-different-approach-managing-our-waysides-and-verges [Accessed August 2017].

How to cite: Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Mowing Case Studies

Case Study CS-M1:

Embankment mowing for bees

Summary

The Environment Agency took an innovative approach to an established mowing regime in an attempt to improve pollinator habitats and reduce costs. A reduced mowing reqime was tested compared to business-as-usual on an earth embankment flood defence on Canvey Island. The altered mowing regime has since been implemented across 120 km of earth embankments in Essex and Kent.

Benefit	High
Engineering	Medium
Ecosystem	High
Cost	Low

How does it work?

The embankments are engineered flood defences, where the landward side is terrestrial grassland habitat. If managed well these assets can provide important habitat for rich bumblebee assemblages, including UK Biodiversity Action Plan species, the Shrill Carder Bee (Bombus sylvarum) and Brown Banded Carder Bee (Bombus humilis). The business-as-usual model was to routinely cut the grassland (up to four times per year) but this trial showed that by leaving the grasses and flowers uncut until at least mid-September, significant biodiversity gains can be made.

Motivation

To improve habitat management to support declining bee populations (as is seen nationally), including UK BAP target species, and a drive to reduce maintenance costs.

Design Innovation / Enhancement measure

Change in management regime – altered or reduced intervention

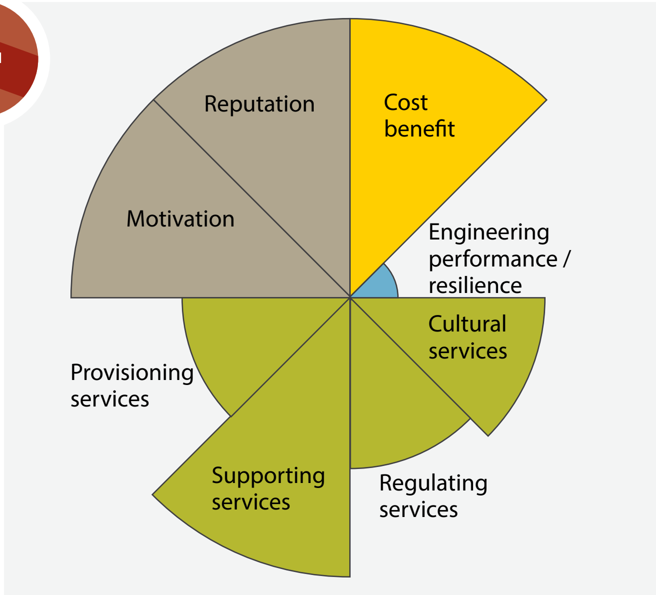

Business-as-usual mowing practice


Changed mowing practice

Benefits

Net cost benefit is expected to be positive, see below. For the Environment Agency the potential cost savings were important but, in addition, the measure was considered to have significant benefit for rare pollinator species. Alternative active habitat enhancement would likely prove more expensive. The ecosystem service value of bees and other pollinators is high.

The scheme has proved successful and it and has been extended further. Research is underway to determine the viability of using the mown material in anaerobic digestion to produce heat, gas and, potentially, electricity, which would further improve the benefits.



Net Cost

The overall cost of this measure is effectively zero or a net reduction compared with business-as-usual. Some additional expenses may occur from mowing thicker, dense grass swards (e.g. more frequent blade sharpening and increased likelihood of breakdowns) but with experience this may be reduced by mowing at lower speeds and mowing with more than one pass with increasingly lower blades. Mowing less often requires fewer people, less machinery and less fuel.

Direct cost of intervention

Currently mowing costs around £250 per kilometre. Average costs for 3 different regimes, therefore are:

- Change in mowing timing: little additional cost (due to increased maintenance of machinery)
- Reduction in mowing frequency from 2 to 1x per year = £250 p/km
- Reduction in mowing frequency from 4 to 1x per year (As per 2) = - £750 p/km

Cost compared to business-as-usual

Cost of mowing per hundred kilometres is reduced by between £25k and £75k year.

A slight increase in equipment maintenance and repair is expected. Mowing more mature grasses can be problematic if the operative is inexperienced. Initial trials in one area showed an increase in the frequency of breakdowns – minor repairs to bearings etc. This can be moderated by additional passes at increasingly lower mowing heights, but this does take more time.

Long-term cost

It is anticipated that there will be no increased cost in the long-term management of these earth embankments to offset the significant short, medium and longer-term savings. Change in mowing timing: little additional cost (due to increased maintenance of machinery).

Maintenance costs are unknown. Post-construction monitoring to measure enhancement effects on local ecology is expected to require 4 person days of monitoring per year (June, July, August and September) for 1-2 years.

Engineering performance, inspection and maintenance

This intervention represents a reduction (or change in timing) rather than a cessation of maintenance by mowing. The grass plays a vital role in the structural integrity of these older embankments and it is essential that it is not compromised. If the grass is too short, the soil may be eroded away by heavy rainwater or overtopping. Similarly, if it is too long then overtopping can rip out the grass and the soil, damaging the embankment. This does not inhibit inspection (which happens at 6 monthly intervals) and has no known effect on engineering performance or design life.

It may be that there is an increased time-pressure when completing one cut late in the season - mowing less often means the grass is longer, thicker and woodier so there is increased load on the mowers and blades may need sharpening, repairing or replacing.

Similarly, the frequency of breakdowns can increase if not properly managed. On average there may be one breakdown a year on Canvey under the traditional regime; however, with the increased load of a late mow (if the spring was wet and the operative is not experienced) this might increase, to double or more minor breakdowns, meaning that the machine is out of commission for one or more days. Most of these are minor repairs to bearings or bushes and can be avoided by doing additional initial cuts at higher blade heights. Inspection is routinely done 6-monthly, with an asset not visible to the inspector for more than 18 months (3 consecutive inspections) deemed to be failing and requiring remedial action. If the embankment is cut in alternate strips down the length at least twice a year, it is possible to inspect each element at least once within that 18-month period.

Ecosystem services

Ecological outcomes for target species have been met through minor changes in maintenance timing and frequency. Statistically robust trials showed overall number of bees increased (almost tenfold) including a significant increase in the variety of species of both bee and pollinator food plants (almost double, from 6 species on the trial site compared to 4 on the standard control sites where mowing was not altered).

The Environment Agency are required to consider biodiversity when developing asset maintenance plans and aim to encourage other landowners to follow. This requires baseline data to make informed choices and the EA have provided guidance documents to support others (e.g. 'Delivering more for pollinators on Environment Agency Land', 2016). Embankments are important resources for a range of species including birds, mammals, reptiles and amphibians, pollinating and non-pollinating insects and other invertebrates. The rarity and/or protected status of some species may mean that altering the mowing regime specifically for bees can be a thorny issue. For example, cutting waterside margins for water vole habitat or delaying cuts for breeding birds may reduce floristic diversity. It is important to establish clear goals and pathways to achieve them using up-to-date guidance and data, and by considering what is most appropriate for a particular location.

The nature and stewardship of much of this kind of habitat (most coastal earth embankments are EA managed) makes it a potentially quick 'win-win' management tool; to save money and provide a refuge for important pollinator species that provide supporting and provisioning services for food production/farming.

Fewer cuts reduces carbon emissions from diesel mowers and allowing the grass to grow longer provides some degree of carbon sequestration. In addition, the clippings could be used in anaerobic digestion for renewable energy production (income generated could be re-invested to further promote and maintain the environment).

As yet no data are available for amenity value. To some the increased biodiversity may provide enhanced aesthetic/visual amenity and in-turn may positively influence nature recreation and leisure values.

Social value

As yet no data are available for amenity value but local wildlife interest groups are very positive about the change. Increased biodiversity may provide some positive nature recreation and leisure values.

Who can apply this intervention / technique?

Any landowner, local authority or government agency with suitable grassland habitat.

Scaling up the benefits

Nearly 120 km of sea wall (118.5 km) in Essex (30% of the 391 km sea walls managed by the EA in the county) is now managed with wildlife in mind and should be beneficial to pollinators to some degree. The cumulative length of sea wall managed with reduced mowing has increased year on year since 2010. There is approximately 2,100 km of vegetated embankment in England and Wales (managed by Environment Agency and Natural Resources Wales). If 25% of the asset stock had a reduction of a single mow e.g. from four to three, or two to one per year, this could yield a net saving of approximately £134,000 per year. The EA also manages or oversees assets on third party land when necessary, so this could add to cost savings.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
COST				●			
ENGINEERING				●			
ENVIRONMENTAL			●		●	●	

Further information

Gardiner T., Pilcher R. & Wade M. (2015). Sea Wall Biodiversity Handbook. RPS, Cambridge. http://www.essexfieldclub.org.uk/portal/p/Sea+Wall+Biodiversity+Handbook [Accessed August 2017]

Gardiner T. and Vetori C. (2015). "Incorporating pollinator friendly grassland management regimes into the Thames Estuary Asset Management (TEAM 2100) programme of works". ECSA Conference, September 2015, London.

Contacts

https://www.gov.uk/government/organisations/environment-agency#org-contacts

The Environment Agency
Fisheries & Biodiversity
Iceni House
Cobham Road
Ipswich
Suffolk
IP3 9JD

Mowing Art of the Possible

Art of the Possible

Flower meadow verges

MOWING

AP-M1

What is the measure?

Switch from mowed to meadow flower verges and central reservations along the city's road network. Pictorial meadows was the company who did the ground preparation and sowed the annual meadow flower.

Primary driver

Budget cuts drove Hartlepool Borough Council to explore the possibility of a combined meadow flower seeding and reduced mowing.

Benefit

The key measured benefits of the altered mowing regime to create flower meadows are reduced costs and improved public amenity. It also helps the council support national policies and likely provides ecological benefits.

Cost

Direct reduction in weekly cutting and litter
Direct reduction in weekly cutting and litter picking maintenance costs from early summer to early/mid-autumn. Business as usual costs £5k per kilometre (mowing and litter picking).The flower meadow saves £1.5k in year 1 (installation), and £3.5k in year 2+ per kilometre. Savings per cut for 10 kilometres of verges is £35k.

Engineering

No impact on engineering function.

Ecosystem services

Cultural ecosystem services have improved from altering mowing practices and creating wildlife meadows on these verges. Similar altered mowing schemes have shown creating meadow flower habitats can significantly improve biodiversity (e.g. Urban Pollinators Project) or improve habitat for and numbers of key species including butterflies and pollinators such as bees (CS-M1). No data on supporting or provisioning ecosystem services were collected here, but other studies have compared meadow flower mixes compared to grass and have found significant ecological benefits from the flower meadows.

Social

Strong public support reported in the local press and social media, including "You so got this right Hartlepool Council. You have brought joy to the community. Everyone talked about it and the wildlife have had a great environment to help them thrive" and "These look beautiful around the town. Well done Hartlepool Borough Council."

Reputation

Since the initial trial in 2014 it has been extended each year and now covers 37 sites "The scheme has had a fantastic response from the public and visitors to the town."

Policy

National Pollinator Strategy, local Biodiversity Action Plans.

Further data

For underpinning research related to this topic see the Urban Pollinators Project: http://www.bristol.ac.uk/biology/research/ecological/community/pollinators/urbanmeadows/

Middlesborough County Council environment scrutiny panel: Maintenance of open spaces.
URL: democracy.middlesbrough.gov.uk/aksmiddlesbrough/images/att1004987.doc

Supplier: http://www.pictorialmeadows.co.uk/about-us/

Video: https://www.hartlepool.gov.uk/news/article/434/video_popular_wildflower_planting_programme_blooms_in_hartlepool

This forms part of Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Urban grassland: Greening a light industrial estate


Urban grassland


Tree nursery

What is the measure?
A novel social enterprise greening and growing scheme on an acre of previously underused land and paving around 11 industrial units on a trading estate between Sheffield and Worksop, Derbyshire. Greening involved a change in habitat from mown grass to urban grassland.

Primary driver
Light industrial areas are often some of the greyest areas of our cities and towns, with little ecological value. This project aimed to improve the local environment for wildlife and people by enhancing biodiversity onsite and creating a native tree nursery for community projects.

Benefit
Saving of £6.5K/annum estate maintenance
This initiative improved biodiversity in an urban area (light industrial estate) typically devoid of green infrastructure and through the plant nursery created jobs and yields an annual cost saving compared to business as usual. It also reduced waste to landfill (through re-use) and delivered a carbon sequestration gain.

Cost
Saving of £6.5K/annum/acre in estate maintenance costs to the industrial; net positive as space was re-purposed to create a successful plant nursery business.

Engineering
There are no engineering impacts from this change in use.

Ecosystem services
Supporting services were measured. The existing heavily manicured lawn and hedge provided little habitat value with no nesting birds, no amphibians, and limited invertebrates. Post-greening the area now hosts a diverse bird population and frogs, toads, newts, grass snakes, dragonflies and damsel-flies flies, water beetles, more than 10 different butterflies, an array of moths, shield bugs, centipedes, gaul wasps, burrowing solitary bees and other invertebrates are found across the microhabitats created. The flora includes over 40 species of native and naturalised trees and a profusion of meadow grasses and flowers. The scheme also provided regulatory services as the tree nursery and associated planting has improved local carbon sequestration. Change of habitat from mown grass to urban grassland may also improve rainfall attenuation. Cultural services were assessed (see social).

Social
The project has employed local people and volunteers in growing a range of plants and products cooperatively; the trees are used for social growing projects on similarly underused or derelict sites. Profits from the nursery reduce annual maintenance costs for the landowner and well-being is improved.

Reputation
The project has won a Gold Green Apple, a Silver Green World award and recognised as a Green World Ambassador. The local businesses have benefitted from an improved local environment and have a certificate showing environmental partnership.

Policy
UK BAP, Urban Forestry Initiatives

Further data
http://media.wix.com/ugd/18479d_2b324dca06b84c8f859c841f8c9f7d23.pdf

Appendix 4: Coastal

This appendix is one of four environment topics covered as part of the NERC funded project report: Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Business Case for Coastal and Estuarine Integrated Green Grey Infrastructure (IGGI)

This business case assesses the existing evidence of integrated green grey infrastructure (IGGI) measures that can support wider implementation in coastal and estuarine locations. It forms part of the NERC funded IGGI frame project outputs (URL: http://eprints.gla.ac.uk/150672/). Costs, benefits and measures of the engineering and ecological performance (called critical success factors) of a range of IGGI alternatives to traditional 'grey' approaches are drawn from operational and research examples across the UK and beyond.

Measures considered include the replacement of existing grey structures with—and creation of new areas of—salt marsh (CS-C1; CS-C2), reed beds (CS-C3) and mudflat (AP-C1), and improving intertidal habitat potential and asset resilience of rock/concrete armouring (CS-C4; AP-C2; AP-C3; AP-C4; AP-C5; AP-C6) and sea walls (CS-C5; CS-C6; CS-C7; AP-C7; AP-C8; AP-C9).

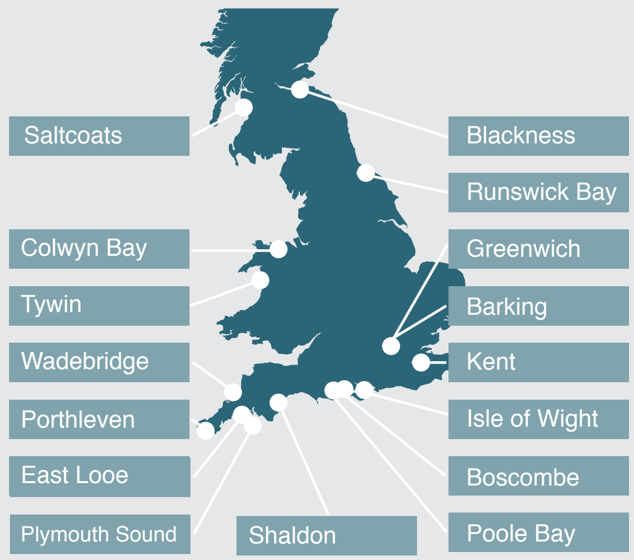
- What are they?
- Where have they been applied?
- What evidence is there to show they work well?
- Will it cost more?
- What are the benefits over business-as-usual?
- What IGGI measures and solutions are there?
- Where are they suitable?
- What are the risks?
- How can I get approval?

When in the design/life of an asset can this be applied?

Most measures can be applied at any stage in the design life of an asset and have been included in strategic flood risk strategies (green engineering as a key performance indicator), as mitigation requirements, strategic design goals and/or as an alternative to traditional engineering during repairs and maintenance.

The measures described can be used in other settings around the UK to maximize wider application. This document will help identify where these opportunities exist.

Where has this innovation been tested or applied?



Evidence Summary

The evidence summary and benefits assessment are a summary of the critical success factors evaluated for all of the coastal case studies and 'Art of the Possible' examples. It is replicated across the four business cases to enable comparison between environmental contexts.

Costs

What do they cost compared to business-as-usual?

Per unit costs for most measures were the same or less, with some research trials costing more. Manufactured versions of trial measures will reduce future costs.

THE SAME

Ecosystem Services

What evidence do we have that they deliver ecosystem service benefits?

To improve biodiversity through habitat creation that supports intertidal saltmarsh, reed bed and rocky shore species.

POSITIVE

Engineering

Are there any risks to design life, inspection or effects on maintenance regimes?

No known risk to design life, and for some species (barnacles, seaweeds, reedbeds and fringing saltmarshes) asset resilience may increase. Inspection and maintenance regimes are unlikely to be impacted.

NEUTRAL

Policy

How does it relate to policy and guidance?

To help meet mitigation requirements such as Environmental Impact Assessment and Habitats Directive.

ACHIEVED

Data Quality

What is the quality of the data underpinning this bundle?

Site specific ecological data for each example was typically high, other data types varied.

MODERATE - HIGH

Social

What are the potential additional social benefits - jobs, cohesion, education etc.?

Improved amenity value, improved community cohesion (CS-C5) and new skills have been developed with vulnerable populations (e.g. offenders).

POSITIVE

Reputation

How have the schemes helped improve public perceptions?

Led to improvements in corporate reputation, gained public support for changes in management and won awards (CS-C6, CS-C7, AP-C3).

NEUTRAL

Asset Resilience

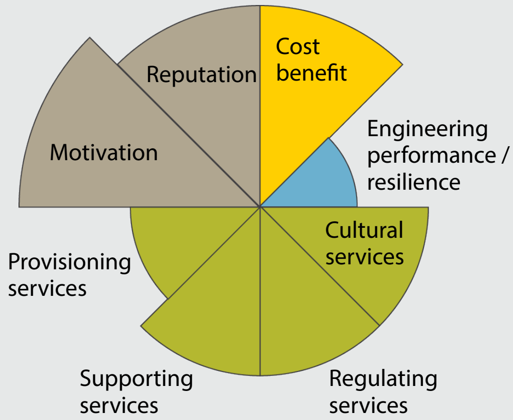
Is asset resilience affected, neutral or improved?

Some species (barnacles and seaweeds) have been shown to improve asset resilience to weathering-related deterioration (AP-C9).

NEUTRAL - POSITIVE

Benefits Assessment

The evidence summary presented above is derived from the examples contained in this bundle, each of which have been assessed using the **Critical Success Factors** guidance developed by this project. The benefits wheels show the benefits of each critical success factor relative to each other. They are a combination of ecosystem services and other important considerations necessary to evaluate IGGI measures compared to business as usual. More detailed breakdown of each element of each can be found below.



Cost
While inclusion of most IGGI measures did increase costs, this was often a small percentage of the overall construction cost. All measures were found to provide (or have the potential to provide) value for money, with additional value gained from increased enhanced ecosystem services, helping meet statutory mitigation requirements, by providing social benefits and additional returns compared to traditional grey engineering.

Engineering value
All of coastal/estuarine IGGI measures reported here have no known adverse impacts on the engineering performance of the hard structures they are on or in front of. Do any IGGI measures have positive engineering benefits? A few coastal/estuarine IGGI measures may have a positive impact on the engineering performance of coastal assets; for example, salt marsh fringes reported here (CS-1 – CS-3) may attenuate wave action as has been proven for larger saltmarshes; mudflats added to a repaired defence helped extend the design life (AP-C1) and; some organisms (e.g. barnacles, seaweeds) have been found to improve the asset resilience of hard coastal structures (AP-C9).

Cultural services
Coastal and estuary areas are attractive to people, and provide a wealth of cultural services from engaging with nature. IGGI measures can be used to generate additional cultural value (CS-C5, AP-C5).

Regulating services
Coastal/estuarine IGGI measures can potentially contribute regulating services such as carbon sequestration, attenuating waves and/or acting as pollutant sinks and reducing deterioration of assets (AP-C9). More research is required to understand and maximise these regulatory benefits.

Supporting services
The primary aim of nearly all coastal/estuarine IGGI measures featured here has been to increase the supporting ecosystem services that hard structures provided through creation of improved habitat for intertidal species.

Provisioning services
Most coastal/estuarine IGGI measures have not been directly designed or tested for their capacity to provide food, energy or raw materials to society. However, their capacity to provide food species or habitat for commercial shellfish and fish species has been shown (CS-C5, CS-C6). They have also been successfully designed to provide food that supports internationally important and protected bird species (CS-C4).

Motivation
IGGI measures can provide significant returns on investment and address the issues that motivated their implementation (e.g. statutory mitigation), by providing useful habitat, engagement and/or aesthetic qualities.

Policy
IGGI measures have been used to provide statutory environmental mitigation (CS-C4, CS-C5, CS-C7, CS-C8).

Reputation
Coastal and estuarine IGGI can help reduce the impact of necessary development that otherwise would reduce habitat and biodiversity. Including IGGI measures in flood risk and development schemes has won several awards, improving the reputation of organisations responsible for the ecological enhancements.

IGGI Measures

Coastal and estuarine IGGI measures (about one third of those included) were derived from the expert knowledge of project partners, information requests and searches, and from the wider academic and practitioner communities. Where required, examples from other countries (that could readily be applied in a UK context) were also included.
The measures are categorised into: (i) evidence-rich and operationally tested case studies, coded CS-C1 to 8, and (ii) 'Art of the Possible' examples that have limited data or which have not yet been applied operationally, coded AP-C1 to 10. Measures are broadly grouped by type (i.e., vegetated, armour, breakwater, sea wall and other) including a range of different structures and incorporating both rock and concrete materials as indicated in the following tables.

Case Studies

Type	Aim of the IGGI	Label	Title
Vegetated	Salt marsh creation on failing defences	CS-C1	Salt marsh on sea defence repairs
Vegetated	Urban re-alignment creating salt marsh habitat	CS-C2	Urban salt marsh creation
Vegetated	Reed beds added in front of sheet piling defence	CS-C3	Intertidal vegetated terraces
Vegetated	Altered mowing on earth embankment defences	CS-M1	Bee Banks
Armour	Use of more ecologically favourable armour	CS-C4	Enhancing armour
Sea walls	Pocket rock pools retrofitted onto vertical sea defences	CS-C5	Seawalls: Vertipools, artificial seashore habitats
Sea walls	Habitat features added under and around a new urban coastal waterfront	CS-C6	Seawalls: habitat enhancement of replacement wall
Sea walls	Niche habitat in stone cladded sea wall repair in a historic conservation area	CS-C7	Seawalls: habitat enhancement of historic wall
Other	Large scale development incorporating enhanced habitat features	CS-C8	Other: Intertidal habitat created around a new development

Art of the Possible

Type	Aim of the IGGI	Label	Title
Vegetated	Repair piling incorporating tidal habitat	AP-C1	Vegetated: Tidal mudflat creation
Armour	Eco-engineered concrete armour units	AP-C2	Armour: Bioblock
Armour	Retrofit habitat added to breakwater rock armour	AP-C3	Armour: drill cored rock
Armour	Retrofit habitat added to rock armour	AP-C4	Armour: Pits and grooves
Armour	Designing habitat into concrete shed units	AP-C5	Armour: Concrete rock pools
Armour	Retrofit habitat added to concrete armour units	AP-C6	Armour: Breakwater
Sea walls	Testing tiles for designing habitat into sea walls and armour	AP-C7	Textured concrete for biodiversity
Sea walls	Testing tiles for designing habitat into sea walls	AP-C8	Textured concrete for sea walls
Sea walls	Using biology to improve asset resilience	AP-C9	Bio protection of sea walls
Other	Retrofit habitat added to outfall cover	AP-C10	Other: eco-enhanced storm water outfalls

IGGI Solutions

IGGI solutions are combinations of one or more measures that can be used together to optimise the ecological potential in a given location. Many of the Case Studies and 'Art of the Possible' reported here have been tested individually rather than as combinations of measures.

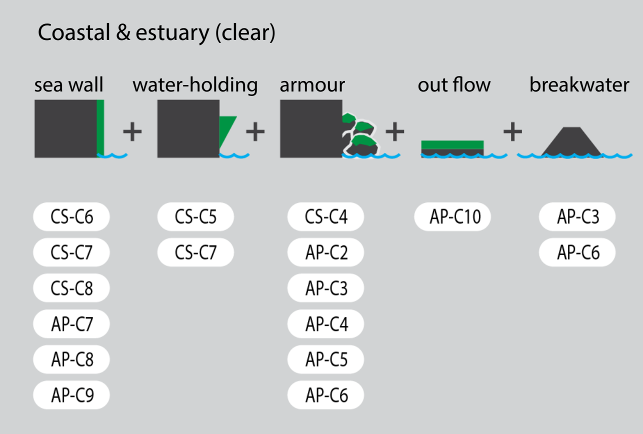
Two case studies from North America illustrate this potential: sea wall enhancement in Seattle (CS-C6) and intertidal habitat mitigation required for Vancouver's Convention Centre (CS-C8). In both examples, a combination of IGGI measures have been successfully adopted to improve both subtidal and intertidal habitats including subtidal habitat creation under the new buildings and piers, and in the intertidal zone by using textured walls, adding water-holding features and designing pedestrian walkways to allow natural light into the marine environment. The Seattle example is also part of a wider initiative to increase use of nature-based solutions; shingle beaches have been re-created to reduce the amount of hard coastal flood alleviation infrastructure in the estuary.

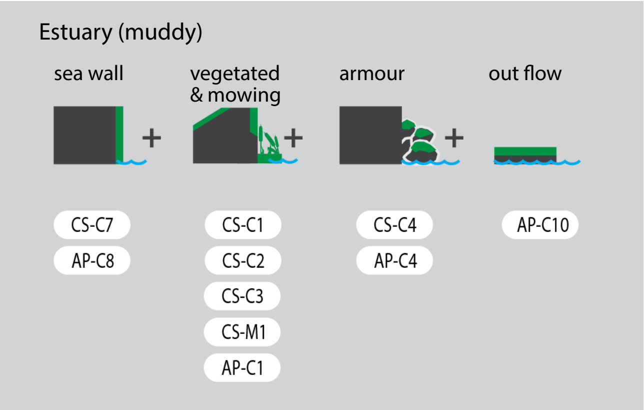
Relevance to other bundles

Coastal examples can often be applied in more than one environment and vice-versa. For example, the Mowing bundle case study Embankment Mowing for Bees (CS-M1) included in this bundle was carried out on a sea defence.

Two coastal examples have been used in historic setting include: CS-C7 is a coastal case study that was successfully applied in a historic conservation area, and AP-C8 was tested on a historic pier; many others could be deployed in this context. All of the coastal examples could potentially be applied in urban areas, where they are appropriate for the local geomorphology, ecology and engineering requirements (see Geomorphology and Engineering suitability section below for details).

We have used expert judgment to identify possible combinations of measures that could be applied to individual coastal and estuarine locations. By using combinations of IGGI measures at one location or strategically positioning them along stretches of estuaries and coasts as part of strategic plans, it would be possible to maximise the ecological potential of hard infrastructure. These measures can also be used alongside softer engineering, nature-based solutions that work with natural processes to improve the ecosystem services provided in urbanised coasts.





How can you get this type of greening approved for your scheme?

The case studies, art of the possible examples and policy links provided here can be used to demonstrate the economic, environmental and social benefits that can be gained from adding IGGI measures to projects. They also provide clear evidence of the policies that have been used as statutory (CS-C4, CS-C5, CS-C7, CS-C8) or non-statutory (CS-C6, CS-M1) drivers. Where no statutory mitigation is required, how else can you get this type of greening approved? Many of the examples only required a willingness to innovate where testing or applying IGGI measures required minimal change in behaviour or practice. Some examples presented here illustrate how simple changes in operational practice (e.g. CS-C1, CS-C4, CS-M1, AP-C5, AP-C7) can yield improvements in ecological outcomes for less, or minimal extra cost.

Physical, engineering and ecological context

The engineering, geomorphological and ecological feasibility of IGGI measures should be considered on a case-by-case basis. When deciding whether a coastal and estuarine IGGI measure is suitable, there are several key considerations:

What types of physical environments have they worked in?
What types of infrastructure can we apply this to?
What are the ecological factors that need to be considered?

Physical settings where IGGI measures have been applied.

What range of physical setting have these measures been applied?

These IGGI measures have been successfully applied from peri-urban to urban environments in open and sheltered coasts, in clear and muddy waters. Specific geomorphic suitability is detailed below.

What types of infrastructure?

These measures have been tested or applied to a range of coastal and estuarine infrastructure including armour, sea walls, harbour walls, earth embankments, stormwater outfalls, piers and sheet piling. These are grouped into 'vegetated', 'armour', 'sea walls' and 'other' according to what type of enhancement they are or what types of hard assets they have been applied on. A description, physical setting, and number of measures of each type are shown in the following table.

What ecological factors need to be considered?

It is important to consider the ecological suitability of the IGGI measures for a given location, and to consider impacts on habitat connectivity, risk of invasives and timing of installation to optimise colonisation by native species. The ecological suitability of different enhancements needs to be considered across the design life of the structure, taking into consideration predicted changes in sea level. As the design life of hard engineering structures is often 80-100 years, it is possible to create future habitat capacity as sea levels rise to reduce the risk of coastal squeeze. Further details are provided on the risks page of this business case.

Type	Description and infrastructure types	Physical settings*	No. of examples	Labels
Vegetated	Addition or altered maintenance of vegetation to earth embankment, concrete, stone or sheet piling defences	Estuarine	5	CS-C1 to CS-C3 AP-C1 CS-M1
Armour	Enhancing rock or concrete armour through material choice, retrofits or designed units	Open and sheltered coasts	6	CS-C4 AP-C2 to AP-C6
Seawalls	Enhancing sea wall design by adding habitat features in new builds or retrofits and adding textures to the wall fabric	Open and sheltered coasts and estuaries	6	CS-C5 to CS-C7 AP-C7 to AP-C9
Other	Enhancing other coastal assets including storm water outfalls and promenade	Estuary, Open Coast	2	CS-C8 AP-C10

* Summary of all settings, for specific geomorphic suitability see below.

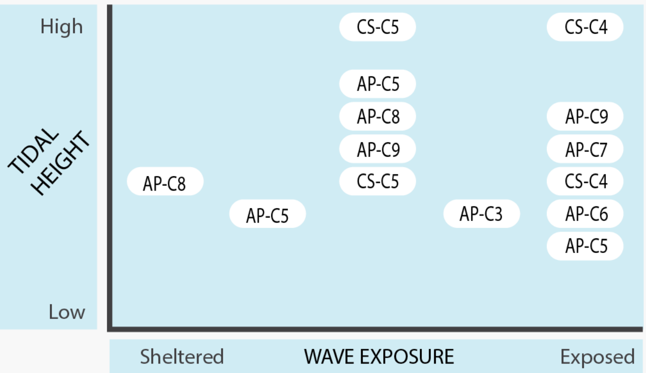
Geomorphic and engineering suitability

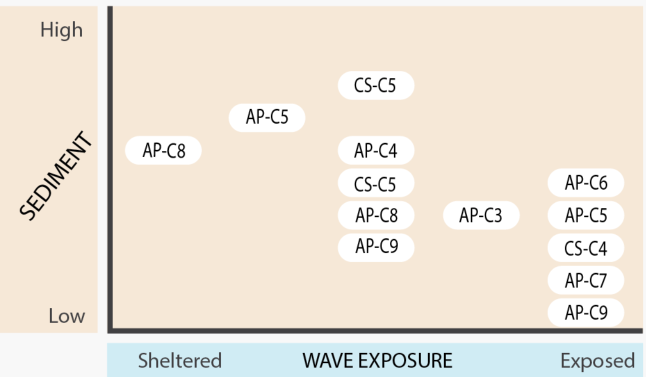
A key question practitioners face when deciding whether to implement an IGGI measure is whether it is feasible in the local geomorphology and engineering context of their project.

The graphs below provide an indication of the tidal heights, wave exposures, sediment loads and (for estuarine examples) water currents that the measures have been applied to date. These have been plotted for open coasts (including harbours within these) and estuaries. Where examples have been tested in more than one place, they are plotted multiple times to show the range of settings they have been tested in. Expert judgment from academics and practicing coastal engineers and geomorphologists has been used to make these graphs. The measures could be applied in a wider range of settings than those shown here; the information only indicates where they have been applied successfully so far.

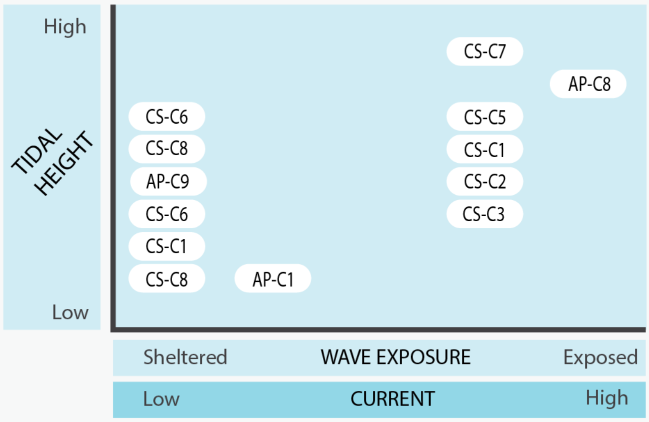
Most of the examples have been deployed between MLWS and MHWS, with MHWN being optimal for many of the measures. An important consideration here is climate change, which will drive sea level rise over the typical design life of engineered structures. There is some opportunity here to consider how IGGI measures may be positioned relative to both the current and future projected tidal frame in order to maximise engineering and ecological performance (see CS-C4).

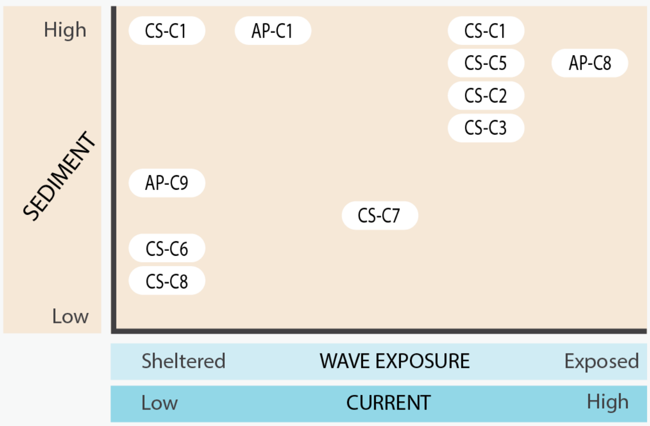
Coastal





Estuary (muddy and clear)





Known limitations or risks associated with these IGGI approaches

The ecological and engineering success of armour and seawall enhancements has been very high globally, with enhancements improving ecological outcomes within 6 to 12 months of deployment relative to business-as-usual approaches. Measures need to be designed for local ecology. Colonisation by native species has been found to reduce the risk of invasive species. There are some risks, design and construction considerations associated with these hard enhancements, as follows:

Risk Factor	Description and Risk Reduction Strategies
Long-term ecological value of material choice	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 chemical composition and the way these materials naturally weather and erode over time.
Timing	IGGI measures should be installed to coincide with native species settlement/recruitment windows to reduce risk of invasives.
Deployment and engineering design	Any planned measures must be carefully evaluated in consultation with the engineering contractor, both to ensure performance is not compromised (there is no evidence that measured considered here have done this) and to consider practicality of deployment (e.g., placing blocks with a particular orientation).
Geography	IGGI measures for rocky intertidal species should be used where these provide important habitat stepping stones or nearby natural habitats; where no natural rocky habitat exists vegetated or WWNP approaches should be considered first.
Ecological connectivity & scale	The effects of IGGI measures on the wider food chain are thought to be positive (e.g. CS-C4, CS-C6) but for far there has been limited research on these impacts. IGGI measures can produce significant local biodiversity benefits but the broader-scale benefits (i.e., regional/national biodiversity maintenance) are less clear. Greatest potential comes from wide-spread uptake of a range of suitable local measures.
Coastal squeeze	IGGI measures can be used (in a limited manner compared with managed realignment) to address coastal squeeze where the policy decision is to ‘hold the line’ (e.g., CS-C4 and AP-C8).

Factors that should be considered for vegetated IGGI measures in the intertidal zone include:

Risk Factor	Description and Risk Reduction Strategies
Sediment supply	This needs to be sufficient for the measure being applied to be successful.
Vegetation failure	Planting or seeding can help reduce the risk of vegetation not establishing quickly.
Coastal squeeze	The design life of measures may be impacted by sea level rise and further mainte¬nance may be required to help lower shore communities ‘move in’. For example, fringing marshes or reed beds designed for mid-upper species (e.g. CS-C1, CS-C3) may be replaced with lower marsh species as sea levels rise.
Ecological connectivity and scale	The effects of vegetated IGGI measures on the wider food chain are thought to be positive but there has been limited research on this. IGGI measures can produce significant local benefits but the broader-scale benefits (i.e., regional/national biodiversity maintenance) are less clear. Greatest potential comes from wide-spread uptake of a range of suitable local measures.
Tidal height	When installing features to re-establish salt marsh, height in the tidal column is key, matching local natural salt marsh can prove effective to determine where to place gabions etc.
Gabion design	Gabion structures should be designed to remain intact for long enough for salt marsh to establish and sediment to be accreted, so that if/when the gabion fails the habitat is not compromised. Wire size, mesh size, welding, plastic coating, galvanisation, filling material and installation methods can all affect gabion design life.

Where to learn more

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Coastal Case Studies

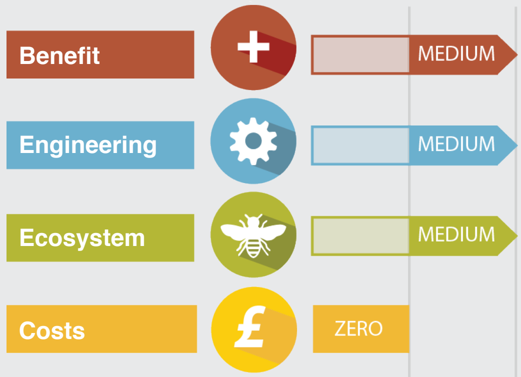
Case Study CS-C1:

Salt marsh on engineered sea defence repair

Summary

The UK has an extensive network of sea defences already in place. Repair and maintenance work accounts for a little less than half the UK Governments planned spending here between 2016 and 2021 (£1bn of a £2.3bn total). Presuming repair costs per metre are significantly lower than new build, the potential for enhancement will be greater in retrofitting existing structures with innovations in green grey infrastructure than in applying them on wholesale replacement or new build scenarios. As an alternative to traditional engineering repairs, twelve experimental stone gabion and clay filled terraces (Fig. 1) were installed in Essex in 2012 by the Environment Agency. The purpose of the repair work was twofold; to protect the toe from wave action and to enhance habitat provision by re-establishing lost salt marsh habitat.

The clay was excavated locally and the borrow pits created additional saline lagoon and/or freshwater habitats.



How does it work?

Sea defences are relatively costly to install, maintain and repair. Climate change predictions describe significant increases in the future frequency and intensity of storm events, while much of the UKs 2100 km of earthen seawall raised after the 1953 North Sea flood event is approaching the end of its design life. The Environment Agency developed some pilot schemes to determine the potential to introduce naturally self-managing systems. Here the traditional repair was enhanced using an extended and raised gabion toe and locally extracted clay backfill to attempt to replace eroded salt marsh.

Where sea level rises inundate these areas within their design life these techniques will be relatively short-term solutions, particularly if the gabions fail and the height of the terrace lowers. However, the repair work is at a similar price to traditional repair, which in itself is not future proofed, and it produces habitat that can accrete material, reduce the impact of chronic and intense wave action (and so reduce the cost of future repair work) is useful in maintaining biodiversity that can improve climate change resilience and provides a source of propagules etc. to spread. It can also provide other valuable ecosystem services, fish nursery and amenity/aesthetic value.

Motivation

An on-site inspection showed that small areas of wall had deteriorated where salt marsh protection was limited or non-existent. In an attempt to regenerate the salt marsh protection, the repaired structure was designed to create habitat (between mid tide level and mean high water neap) that encouraged colonisation by salt marsh species.

Design innovation / Enhancement measure

Replacing traditional like-for-like sea wall revetment repair materials (e.g. Essex blocks or open stone asphalt) with gabion baskets and clay back fill in a toe design that helps re-establish salt marsh habitat in a sheltered estuarine setting.

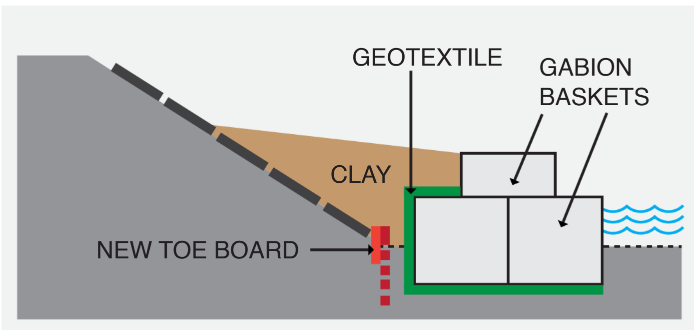
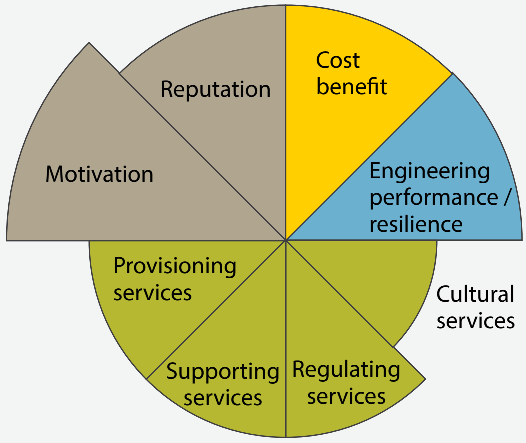


Figure 1. Example of repair work, new berm backfilled with clay behind stone gabions. The clay area provided habitat for saltmarsh plants.

Benefits

The trial vegetated terraces were only very slightly more expensive than traditional repair costs and have the potential to provide significant protection to the defences as well as a range of ecosystem service benefits.

Estimates in 2010 gave ecosystem value figures of, on average, £960 per ha per year for salt marsh (and a range from £200 - £4,500). These values relate to habitat gains (Brander et al, 2008). However, if the area is/could be used as commercial fish nursery, value may be higher. This could be estimated by calculating the difference between the value of land in its current use and the value of land as a nursery. Alternatively, one could estimate the annual revenue of a fish nursery.



Net Cost

The net cost per metre is around £660 to repair revetment and add gabions backfilled with clay.

Direct cost of intervention

If only toe repair is required, the green infrastructure element will form the entirety of the repair at similar cost to traditional repair work. Where other repairs are required further up the revetment then the GI will be an intrinsic component (the gabion baskets and clay backfill) of this larger work.

Cost compared to business-as-usual

To retrofit a terrace it would cost around £660/m, where additional costs are for the gabion baskets and clay backfill. This is very similar to the traditional blockwork repair to the toe that typically costs £631/m (Cousins et al, 2017).

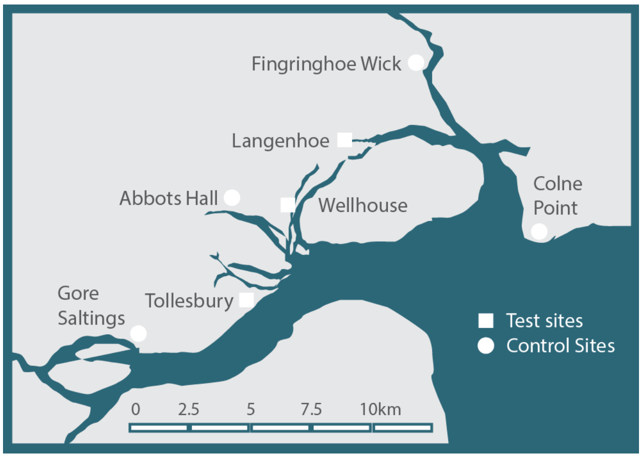
Long-term cost

Salt marsh can protect against wave and storm action. Where significant width of salt marsh becomes established successfully, it may be possible to reduce the height of landward coastal defences. The potential for narrower, fringing saltmarshes (as described here) to provide this benefit needs further testing but they could reduce maintenance and repair costs of the coastal walls they front by buffering waves. Increased storminess may mean that including naturally resilient elements in becomes increasingly important. In the longer term, a limiting factor or these measures may be the ability of the terraces to maintain their flood alleviation and ecological value as sea level rises. These risks also exist for traditional approaches; where space allows future flood alleviation can be set back to provide more intertidal habitat to help maintain ecosystem service benefits (AP-C1).

Engineering performance, inspection and maintenance

The combined gabion and saltmarsh habitat was designed and constructed by the Environment Agency, through their coastal management team, and installed by EA-approved engineering contractors.

The overall integrity of the scheme was tested under significant tidal and storm surge conditions in early December 2013 with no loss of structural integrity. Research shows there was some small channelling at the ends of each section where water flows increased scour, and while this removed some clay sediments, it had no impact structurally. It was postulated by the research team that this could be negated by a slight change in design. They advise a return gabion closing off any flows between the ends and the sloped surface of the berm.



Ecosystem services

Over 22 months of monitoring by the University of Essex found that each terrace provided a narrow strip of otherwise unavailable sediment substrata that had potential to support salt marsh vegetation. Though salt marsh development can take time to fully develop, seven of the twelve terraces showed increased colonisation by salt marsh plant species, up to 85% coverage after 22 months. Factors such as the depth of the gabion, the proximity to existing salt marsh, flow rates and sediment compaction were important factors influencing the ecological success of the design. Studies suggest this could be improved with more precise placing – right level.

An initial driver for the scheme was to mitigate for habitat loss, which was achieved (Cousins et al, 2017). The provision of wider ecosystem services requires additional study. Local salt marsh does provide some habitat for fish (refuge, nursery and feeding) and feeding, roosting and nesting sites for various species of shorebirds.

Recent research suggests relatively small areas are proportionately more productive as fish fry refuges than large areas. Some salt marsh plants are edible and there is some commercial interest in growing samphire, which could increase the benefits of this approach compared to business as usual.

Social value

Although no social value data were gathered within the study, there is evidence to suggest there is some amenity value in natural habitats like salt marsh; landscape aesthetics and as sport and commercial fish habitats.

Who can apply this intervention / technique?

Any landowner, local authority or government agency with suitable grassland habitat.

Scaling up the benefits

Additional trials are currently underway in the South East of England to improve the evidence base and spatial area that it has been tested.

Annual engineering inspections show that on average around 5% or more of the existing infrastructure is failing, so there is potential to include this approach as part of ongoing repair activity. In many areas the installation costs are prohibitive for individual spot fixes (lengthy permitting processes, access (plant and materials)). It is thus better suited as part of larger or more strategic repairs.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY						
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COST		●			●		
ENGINEERING		●			●		
ECOSYSTEM SERVICES			●		●	●	

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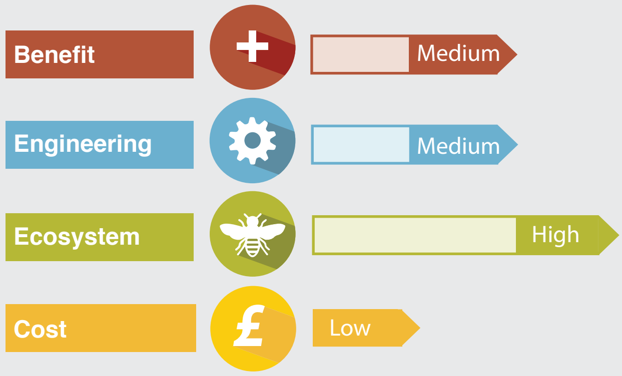
Case Study CS-C2:

Salt marsh creation in an urban area

Summary

Under the Government Sustainable Communities Fund, the Environment Agency aimed to create new mudflat and salt marsh to increase flood storage capacity of Barking Creek (and tributary of the River Thames) and provide Biodiversity Action Plan habitat.

As the area is heavily urbanised, substantial saltmarsh and mudflat habitat had been reclaimed over the past few hundred years. This scheme improved the social, amenity and ecological value of an underused and undervalued species poor grassland site that had limited ecological, social or flood storage value by re-creating one hectare of mudflat and saltmarsh Biodiversity Action Plan habitat. The habitat was built alongside improvements to flood alleviation, adding amenity and ecological value such as creating nursery habitat for commercial and non-commercial fish species and increasing flood storage by 15,000 m³.



How does it work?

Small-scale set back of sea defences on an estuary. Original sea defences were deliberately breached, creating tidal backwater habitats in a sheltered, high sediment load estuarine setting. A 0.1 ha tidal mudflat between mean low water spring (MLWS) and mean low water neap (MLWN) and a 0.9 ha of saltmarsh habitat between MLWN and mean high water neap (MHWN) were re-created, adding 15,000 m³ of flood storage capacity. Brushwood and coir revetment structures were installed, and the structure was allowed to colonise naturally as well as by seeding the upper slopes using locally collected seeds from the river's own seed-bank.

Motivation

This project aimed to increase flood storage capacity on the Thames and provide valuable for local Biodiversity Action Plan saltmarsh and mudflat habitat. It also aimed to address social factors: to improve access via the creation of a new river pathway; to improve the aesthetics of the riverside-area; to provide educational interpretation boards for the general public. Barking Creek is recognised as a valuable feeding and refuge area for a variety of fish species e.g. European flounder, European eel, bass, sand smelt and also supports some commercial European eel fishing (Colclough et al., 2002). Enhancing and extending the upper intertidal habitat was aimed at benefiting these fisheries.

Design Innovation / Enhancement measure

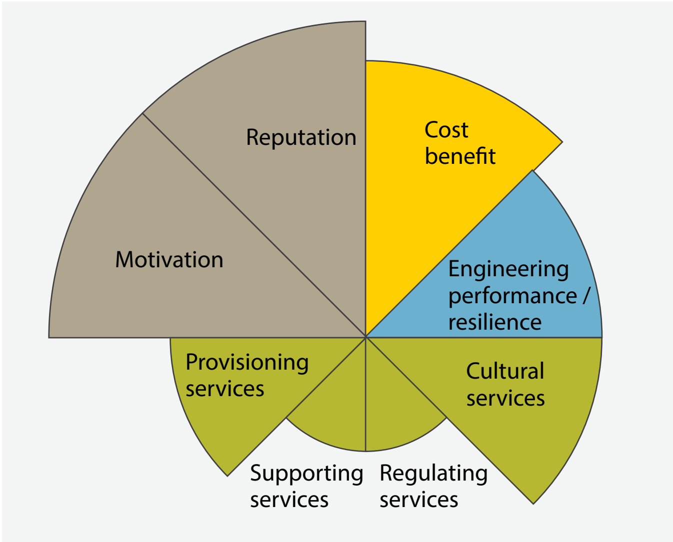
Losing land to water to improve biodiversity and visual amenity. A formal green space behind the tidal defence was changed to create a tidally inundated area. The technique had been used previously, but combining hard engineering around the site and much softer techniques (such as brushwood) ensured the tidal setback remained stable.

Benefits

The benefits of the flood mitigation element were carefully assessed by the Environment Agency to outweigh the costs. The greening elements have proven successful in stabilising the area and have largely improved the aesthetic.

Although a relatively small measure, the inclusion of the ecosystem enhancements will likely have had some localised effects on the environment by providing flood storage, sequestering carbon and helping to clean run-off water (by trapping pollutants) before it reaches the Creek.

Mudflat and saltmarsh rapidly established after installation, improving habitat provision for overwintering birds and providing nursery sites and food for commercially important fish. No data are available regarding public perception of the scheme, but similar enhancement work on the Thames and its tributaries (as well as rivers in other cities) has proven to have positive social affects. There is limited data evidencing these benefits to date, but the EA is currently measuring some of the Water Framework Directive related ecosystem services that these enhancements are providing in the Thames region.



Net Cost

Based on 2006 construction costs, for the habitat re-creation aspect of the scheme only, the net construction cost per m^2 is estimated to be ~£108. This compares to a total cost of approximately £146 per m^2 for the combined flood alleviation and habitat re-creation works carried out at the site.

Direct cost of intervention

The construction costs for the habitat re-creation part of the scheme was £210K; this was completed alongside a small amount of flood alleviation repair works that cost £74K (2006 prices). As a result significantly greater enhancements were delivered at this site than would have been possible had the projects been delivered individually. This approach also made best use of the design consultant and contractor services, reducing construction costs. There were also no land purchase costs as the land was already owned by the Environment Agency (EA), providing substantive savings (£900/m^2, 2017 land prices).

Cost compared to business as usual

This case study was funded via environmental improvement funding (for sustainable communities) from central government, and this option was the deemed the most cost effective during options appraisal. As the EA owned the land, the cost was reduced by approximately £900/m^2 (£9M per hectare, 2017 prices) compared to having to purchase off-site compensatory habitat. The re-created creek, footpath and landscaping occupied 40% (1 ha) of the total ~2.5 ha owned by the EA. This case study illustrates the potential for small-scale intertidal habitat re-creation projects to provide on-site net ecological gain, reducing the need for costly off-site mitigation. Off-site mitigation would have cost a minimum of £9M (2017 land prices) to purchase land to re-create the habitat elsewhere.

Long-term cost

Long-term maintenance of the scheme is not expected to cost more than for other managed realignment schemes elsewhere as the saltmarsh community is well-established and the gradual slope of the design will make it easier for species to adapt as sea level rises, likely reducing future maintenance costs.

Engineering performance, inspection and maintenance

The existing land level was excavated away to slopes less than 1:7, and clay capped with the newly created sediment surface stabilised with natural posts and brushwood (Environment Agency, 2008). This provided a stable substrate for natural and seeded (2 g/m^2 of locally collected seeds) colonisation that has proven very successful, with 40 cm of sedimentation within 6 months of installation and swift vegetation growth. The set-back has required little or no maintenance since it was created 11 years ago.

This case study demonstrates that well-designed and installed natural brushwood and vegetation bioengineered system can provide low cost, self-regenerating flood storage.

Ecosystem services

Prior to regeneration the Creekmouth site was terrestrial grassland with patches of scrub and invasive *Fallopia japonica* (Japanese Knotweed), providing few ecosystem services for nature or society. The regeneration scheme included habitat re-creation, educational and recreational elements. After breaching, the intertidal area was left to colonise naturally, rapidly attracting many native species. The EA identified four broad ecological zones: (1) the terrestrial zone – approximately 0.5 m below spring high tide level. This comprised of common herbs, including *Lotus corniculatus, Plantagomajor, Tripleurospermum maritimum, Chrysanthemum leucanthemum, Artemisia vulgaris* and *Sanguisorba minor*; (2) the marginal wetland zone – where tidal inundation determines species composition including *Aster tripolium, Apium graveolens, Beta vulgaris, Ranunculus scleratus, Elymus pycnanthus, Agrostis stolonifera* and *Apium graveolens*; (3) and (4) two lower zones of sedimentation where maximum silt deposition occurs, dominated by *Phragmites australis* and *Scirpus maritimus*. Locally, these foreshore habitats are known to be important for overwintering birds such as teal, shelduck, tufted duck, wigeon, gadwell, shoveler, pintail and little grebe. Common whitethroat, sand martins, linnet and oyster catchers were recorded breeding in the foreshore near this scheme in 2000. With the plant species that have colonised the site, it is highly likely that these bird species have also benefitted from the additional habitat.

Estimates suggest that around two thirds of commercially important fish caught are dependent on estuarine habitat in their juvenile years and that the Thames Estuary is a key nursery site for fish (Colclough et al. 2002) where tidal creeks such as Barking provide specialised refugia (Tyner, 1993). There is clear evidence that mudflat and saltmarsh habitat provides fish refugia that are important for maintaining and improving commercial fish populations. Saltmarshes are very dynamic habitats, and short-term quantitative estimates can be highly inaccurate, but fish sampling at realignments similar to this elsewhere in the inner Thames (see CS-C3) have shown there were increases in commercial fish species.

These more natural habitats provide aesthetic and ecological benefit, helping to create a better link between the river and the surrounding area. This was aided through the provision of 310 m of footpaths within wildflower-rich parkland as part of the scheme; these have provided, closer access to the river and the new estuarine habitats. Interpretation panels were also installed to help local users learn about estuarine ecosystems and the value the newly created habitat provides, improving the cultural ecosystem services provided by the site.

Social value

The triple-win benefits of increased flood capacity in an urban area, habitat creation (with commercial and aesthetic value) and improved access make this a potentially appealing innovation.

Who can apply this intervention / technique?

Land managers with responsibility for riparian areas prone to flooding. Specialist guidance may be required where flooding could cause damage to property or infrastructure.

Scaling up the benefits

An increasing array of more environmentally sensitive flood management tools are being developed and described in guidance from "No Intervention" options through to "Working With Natural Processes" (WWNP) and green, or green/grey options. Many projects can include a number of these.

This mainly green grey project was an attempt to improve social, environmental and, to some degree, economic aspects of the Creek mouth, e.g. flood storage to alleviate flood risk, provide environmental education and improve habitat for commercial fish stocks.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

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COST		●				●	
ENGINEERING			●			●	
ECOSYSTEM SERVICES		●				●	

Further information / Contacts

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joanna.heisse@environment-agency.gov.uk

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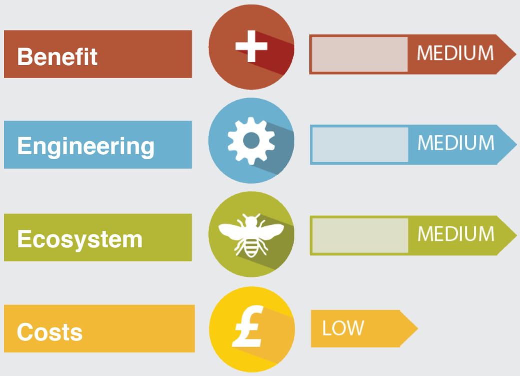
Case Study CS-C3:

Intertidal vegetated terraces

Summary

Only 2% of natural habitat remains along the Thames. The traditional engineered defences that have been employed over many decades do not reproduce the range or quantity of habitats they replace, nor do they encourage colonisation by native species.

Two areas of inter-tidal terracing were created on the Greenwich Peninsula, London; one at Blackwall Point and the other at the Eastern River Wall.



How does it work?

This enhancement is a structurally engineered design combining both IGGI and traditional grey engineering elemetns. At two locations in Greenwich, sheet pile wall was cut down to near beach level and capped and either sheet piling or a concrete wall was installed between 7-15 m inland. This extended the area between Mean High Water Neap and Mean High Water Spring tide levels, where the newly created intertidal space was designed to provide saltmarsh habitat.

Motivation

The sheet piling was approaching the end of its design life and the area was soon to host the Millennium celebrations at the Dome. The area was heavily industrialised and aesthetically unappealing. The Environment Agency felt there was a good opportunity to repair the sheet piling and improve the area using best practice for nature conservation, fisheries (nursery, refuge and marginal feeding zones) and environmental education. A stated aim was "*To develop and maintain healthy, diverse and attractive inter-tidal ecosystems on the terrace in the long term; to ensure that their ecological development was recorded and disseminated to help other river flood schemes develop*".

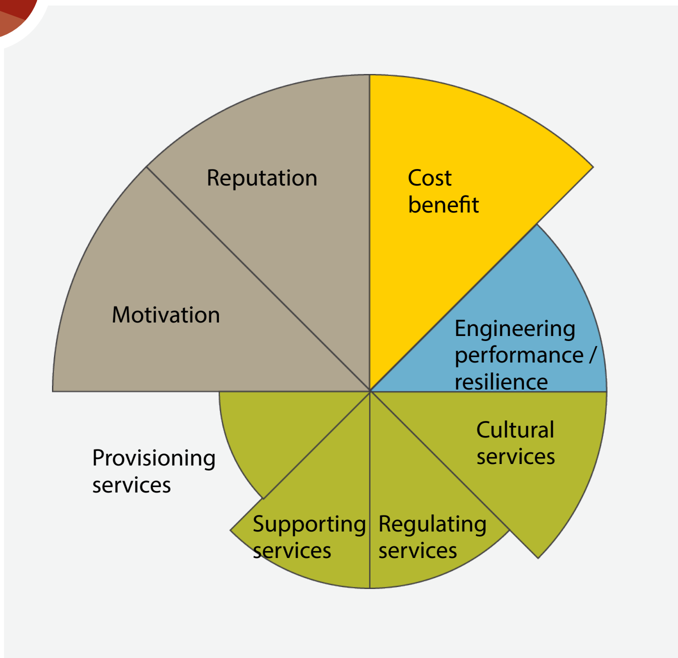
Design Innovation / Enhancement measure

Existing sheet piling that was in poor condition was cut down to near beach level and capped. New sheet piling or a concrete wall was installed between 7 – 15 metres inland. This space between the old and new sheet piling (or concrete wall) was then used to create stepped and/or sloped saltmarsh habitat between mean high water neap (MHWN) and mean high water spring (MHWS) tide levels. Stepped terraces were created using gabions or wooden piles at slopes of 1:7 or less and in-filled with sediment of similar characteristics to that found locally. These areas were planted with saltmarsh species or allowed to colonise naturally.

Benefits

Designed to maximise aesthetic value, this project saved around half the business-as-usual costs and provided a relatively small but important and visually appealing habitat. The wider area was heavily industrialised, urban and densely populated, and was to become the focus for the UK's Millennium celebrations. The cultural services have not been monitored though there is anecdotal evidence that the sites provided significant aesthetic appeal.

Extrapolation from other small-scale estuarine habitat regeneration projects suggest these provide significant benefits for fish (for nurseries, refuge and feeding). The vegetation provides some locally significant primary production and nutrient recycling services alongside potential capacity for run-off retention and amelioration of contaminants/pollutants. The vegetation can accrete material and attenuate erosion from waves. Elsewhere, enhanced riverfront schemes have been shown to uplift property prices by 3 to 10%.



Net Cost

The net per m cost of the terraced saltmarsh habitat component of the £12m scheme is unknown.

Direct cost of intervention

The direct cost of building the terraced habitat included the costs of removing and capping most of existing sheet piling, installing replacement sheet piling and/or concrete wall inland, creating and planting the terraces. Some initial monitoring and replanting of the scheme was also required, along with building footpaths and signage. These costs amounted to £12M (1998 prices), which equates to approximately £17K per linear m.

Cost compared to business-as-usual

The cost of the structurally engineered design involving both newly built set-back defences and saltmarsh terraces was approximately half the anticipated cost of removing, disposing of and replacing the existing sheet piling. During the options appraisal for the scheme (1996 prices), a few different options were estimated over a 60-year whole life cost including full height replacement of the old sheet piling with new sheet piling (£6000 per m) or encroachment using battered terracing (£8100 per m). This compared to £3400 per m to lower the sheet piling by 4.0 m and create an inclined terrace (Atkins, 1996). Discussions with the Environment Agency team have suggested that replacement sheet piling in this estuarine setting would cost between £10K - £24K per m now (2017 prices).

Long-term cost

After some initial difficulties with disturbance of the installed materials (geotextiles, vegetated matting and planted material) the terraces are largely self-managing. Where amenity planting was done there was a need for some maintenance and certain species became dominant, although this could be prevented in future installations. Litter and debris can accumulate quickly and needs to be removed.

Engineering performance, inspection and maintenance

Overall considered to be highly successful, a benchmark design. Some deterioration - gabions breaking down after ten years (thought to be because welded gabions were chosen over woven or plastic coated) and repairs/renewals may be necessary to retain certain terraces.

Initially some wave action led to lifting of the matting and extraction of many young plants, necessitating some replanting, though there was also considerable natural colonisation. Design modifications mean this could be prevented in future installations. Freshwater outfalls exposed the reinforced geotextile mat and eventually looked unsightly.

Overall performance was found not to be reduced – terraces are able to withstand tidal and wake forces. Inspection and maintenance still possible.

Ecosystem services

As the only intertidal vegetated habitat in this part of the Thames, the Millennium Terraces provide a valuable area of habitat. Re-planting directly into the substrate without erosion matting was most successful with Common Reed, Grey Club-rush, Sea Club-rush and Sea Aster, with several species surviving well below or above the main 'saltmarsh zone'. Excessive dominance by Common Reed was seen as the result of a failure to install rhizome breaks.

A design feature – the stepped terraces – appeared to stop some fish from moving up the terrace floor (sampling in 2003 showed the terraces with steep angle frontages restrict demersal species, e.g. Flounder. Other smaller fish like Gobies moved onto the terraces during inundation. Smelt (Osmerus eperlanus) were found deep in the vegetation at the back and front of the terraces. Extensive monitoring has shown intense use of the terraces by Sea Bass and other species.

The additional habitat also provides other opportunities for biodiversity including pollinator species and their food plants. The site provides some degree of water quality control (retaining and remediating run-off), and because the project was an exemplar and the monitoring is on-going, there is some cultural and scientific value. Some aesthetic improvement also was achieved.

Social value

Thought to be high but not assessed directly. In 2001 the Greenwich Peninsula Management Plan stated “the terraces serve a major function in terms of visual amenity for pedestrians, the inhabitants of Central Village and visitors to the Dome”. Economic valuation of urban riverside enhancements show property price uplift in the order of 3 to 10%. This has not been directly meas¬ured here, but the terraces have been used in property marketing literature.

The terraces were constructed primarily for the purposes of nature conservation, fisheries and environmental education. There is no unauthorised access to the terraces and no navigational or mooring function, nor local fishing access. Where ecological and safety constraints permit, access could be improved in other similar schemes by a variety of slipways or floating pontoons.

Who can apply this intervention / technique?

Those involved in installing or repairing riparian, estuarine and coastal defences that currently provide low quality/ low biodiversity habitats.

Scaling up the benefits

A key goal of the scheme was to disseminate the monitoring data: to assist in the guidance and development of other river flood schemes in London and elsewhere.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

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ENGINEERING					●		
ECOSYSTEM SERVICES		●			●		

Further information / Contacts

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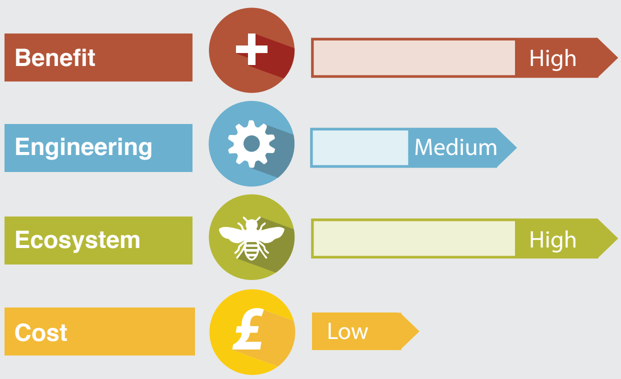
Case Study CS-C4:

Open coast habitat creation using rock armour

Summary

A decision was made to repair and replace the extensive sea defences around Hartlepool, UK. The Headland coastal defences protect 562 residential, commercial properties and key heritage features. These defences, north-east facing vertical masonry and concrete walls were in poor condition, frequently overtopped during storms and suffered significant damage during the winter 2013/2014 storms. The project, funded by the Project for Accelerated Growth (PAG) Scheme, included a partnership between the Environment Agency (EA), Hartlepool Borough Council and PD Ports, with support from the nature conservation body Natural England (NE) for the ecological enhancement as Habitats Directive mitigation.



How does it work?

The design of the scheme included innovative techniques of passive and active ecological enhancement to provide habitat that provided sufficient habitat to support wintering feeding populations of internationally designated bird species. This involved a combination of measures:

- Passive enhancement involving: a) ecologically favourable material choice within cost and engineering constraints and b) placing specially selected naturally textured stones in positions to encourage colonization.
- Active enhancement involving the use of textured form liners (similar to those in AP-C8) when casting wall panels.

This project aimed to build on wider research showing ecologically engineering artificial habitats, either during the construction phase or retrospectively, can result in higher species diversity. Data from on-going comparative studies underpins this case study. University of Glasgow, University of Oxford, Hartlepool Borough Council and Mott MacDonald carried out pre-construction baseline surveys, both at the site and at a neighbouring control site. Monitoring is ongoing; results of the passive enhancement are currently available and are presented here.

Motivation

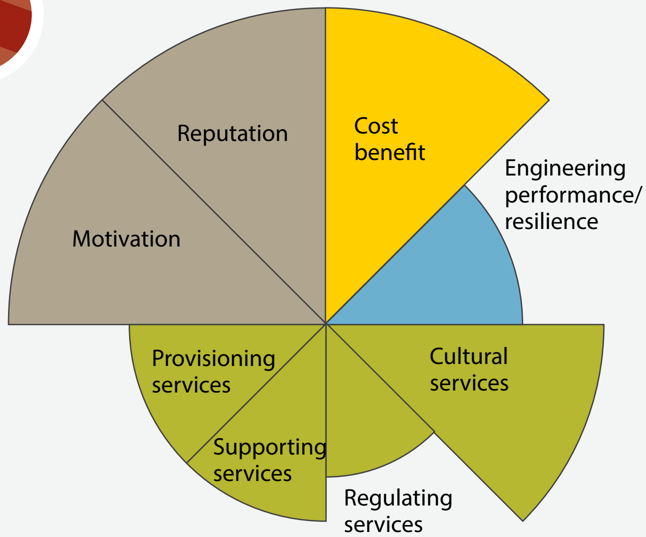
The coastal protection works are within a Ramsar site (JNCC 2008) and a Site of Special Scientific Interest (SSSI) (Natural England 1997) that contains some of the most important overwintering bird feeding sites in Britain for designated species. A key requirement was thus to provide mitigation under the EU Habitats Directive to reduce the ecological impact of habitat losses associated with extending the toe of the defences seaward. The aim was to ensure no adverse effects on the integrity of a Natura 2000 site designated for internationally important waterbirds. It also sought to minimise future habitat losses due to sea level rise and coastal squeeze.

Design Innovation / Enhancement measure

In order to achieve a habitat outcome that most closely mimicked the existing rocky shores at Hartlepool, and offered feeding opportunities for the waterbirds, the scheme employed a combination of passive and active multi-scale enhancements. Passive techniques (e.g. choosing construction materials based on lithology and surface roughness) were used on the rock armour and more active enhancements (similar to AP-C8) sought to improve the habitat and aesthetic value of the wall panels (similar to CS-C6). Both are simple and inexpensive, adding no or nominal additional costs compared to business-as-usual. To date, it is also the largest and only the fourth known operational ecological enhancement of hard coastal infrastructure in the UK (after Shaldon in Devon, the Isle of Wight and Bournemouth) (Naylor et al. 2012; Arc Consulting 2016).

Benefits

The ecological enhancements were crucial to gaining approval for the scheme from Natural England; they allowed the local council to access time-limited central government funding. Ecologically, early monitoring of the scheme suggests that it is meeting the aim of providing a cost effective, ecologically sensitive coastal defence with long-term enhancement value that meets the needs of the local businesses and residents. The textured walls and the ecologically favourable rock armour are performing as well as traditional techniques having survived strong storms during the winter of 2017. It demonstrates it is possible to ensure that the planned engineering resilience to storm events is achieved with the additional benefit of maintaining ecological value and thus providing on site mitigation.



Net Cost

Overall the net cost of the IGGI aspects of this coastal flood alleviation scheme are close to zero. For the passive enhancement, selecting ecologically favourable granite was not onerous nor more expensive, where the recommended rock characteristics were available within an acceptable distance from a customary supplier and could be delivered on time and in sufficient quantity. For the rock armour that was enhanced further via positioning, no extra costs were incurred during construction. Good communication and planning meant that the additional complexities in selecting and placing the appropriate stone blocks to maximise habitat did not add to the build time or costs. For the active enhancement of wall panels using textured formwork, there were modest additional costs, which are detailed in AP-C8. Ecological monitoring has been funded through collaboration with the Universities of Glasgow and Oxford.

Direct cost of intervention

Close to zero. For the passive enhancement, existing expert judgment was used to select suitable rock material from the supplier, and experienced operators placed the rock armour on-site. This did not incur any additional cost as the operator had to make minor adjustments to the deployment procedure to position the rocks to maximize ecological potential. For the active enhancement, it cost an extra £8-£30 per m^2 compared to plain cast formwork (see AP-C8 for more detail).

Cost compared to business-as-usual

No significant increase in cost. Enhanced rock was placed at conventional rates (10m/day/tide). The scheme also won timely approval because of the enhancements – this allowed the council to access time-limited central funding, reducing the local cost burden.

Long-term cost

No additional long-term cost anticipated. This is essentially an adaptation of business-as-usual to accommodate for significant bird population habitat and pre-empt coastal squeeze. If the longer-term ecological outcomes need improving, ideas from AP-C4 – AP-C6 can be added.

Engineering performance, inspection and maintenance

The scheme has a design life of 80 years. Aside from the resulting additional colonisation and biodiversity associated with the IGGI aspects there was no inherent difference in the design, materials or construction that would significantly change the engineering performance, or alter how the structures are to be inspected or maintained. Extensive discussions between the design team, scientists and the construction team ensured benefits were maximised and engineering function was not compromised within the project's budget.

Ecosystem services

Only supporting ecosystem services have been measured in this study. Prior to construction, fourteen bird surveys were carried out over 4 years, and a Phase 1 habitat survey (14 transects over 7 kilometres) undertaken at the site in 2014. These data were compared to two previous biotopte surveys (2003, 2010) and a similar study of a neighbouring rock revetment installed in 2002. Access to the foreshore for baseline monitoring was gained during year 1 of construction where quantitative baseline data were collected on horizontal and vertical shore platform areas not disturbed or covered up by construction. Post-construction, the partially enhanced and enhanced rock armour areas of the scheme were monitored 12-18 months post-colonisation (n = 4, 25x25cm quadrats per area).

Preliminary post-construction monitoring results (12-18 months post-installation) suggest that the new passively enhanced rock revetment has the same biotope as the baseline natural shore platform (Naylor et al. under revision). Species richness on the rock armour (both types) was statistically lower than found on the baseline shore platform. The enhanced areas also appear to support quicker succession, and have species densities more similar to baseline conditions than unenhanced areas of the revetment. For example, key prey species (the limpet *Patella vulgata*) on enhanced rock armour, showed statistically significant abundances similar to the baseline shore platform and significantly higher numbers of limpets than found on partially enhanced rock armour. This preliminary data suggests that passive ecological enhancement approaches can help mitigate ecological impacts of new rock revetments in designated Natura 2000 sites, over timescales as short as 18 months. Monitoring of the scheme is on-going via a University-Local Government collaborative project, and this will provide valuable longer-term data on ecological performance and the ecosystem services. Notably this IGGI measure maintains ecological resilience of Natura 2000 sites now and in the future as coastal squeeze is a larger risk factor, whilst providing a socially desired level of coastal flood and storm alleviation.

Wider ecosystem services stem from the cultural and social value of protected species. There are clear scientific justifications for maintaining Natura sites and other similarly rare and endangered ecosystems, and many people will see an intrinsic value beyond, in what they can provide in terms of cultural service, for social cohesion and identity. The sites proximity to over 500 homes brings the sea and internationally important bird populations into the everyday lives of the locals. It provides services for health, identity and learning, recreation and tourism. The overwintering bird populations are important as a local amenity, for ornithologists, naturalists, amateur nature lovers, and the wider community.

Social value

The public strongly supported the hold the line coastal management policy as the area contains significant cultural heritage, including a scheduled monument, the Heugh Gun Battery; the scheme aims to reduce coastal erosion risk to the community and increase amenity value of the frontage over the next 100 years with the added benefit of maintaining habitat (and thus social value) of the site for overwintering birds. Construction will last for 5 years and is on-going so social perceptions of the ecological enhancements are unknown.

Who can apply this intervention / technique?

The passive and active enhancements carried out here are part of a suite of possible IGGI measures that can be applied to a range of coastal assets include flood alleviation, piers, harbours, stormwater and energy infrastructure. See the coastal and estuarine IGGI business case for more ideas. Many of these are inexpensive relative to the benefits gained and can involve simple modifications to existing engineering practice (e.g. the use of textured formwork).

Scaling up the benefits

There is potential for these and other coastal IGGI measures to be included in conditions for planning agreements and integrated as guidance into Strategic Marine Plans and Local Development Plans for coastal developments. It is also possible to apply these recommendations as part of future tenders, so that contractors are required select ecologically favourable rock armour using active or passive enhancement techniques (see also AP-C2 to AP-C6) and/or to texture smooth concrete surfaces for ecological gain (e.g. CS-C6, AP-C7, AP-C8).

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY Hartlepool passive and active enhancement measures						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
COST			●			●	
ENGINEERING			●	●			
ECOSYSTEM SERVICES			●	●		●	

Further information / Contacts

Naylor, LA, MacArthur, M., Hampshire, S., Bostock, K., Coombes, MA, Hansom, JD, Byrne, R. & Folland, T. Accepted. Rock armour for birds: Ecological enhancement of coastal engineering to provide food for birds, Hartlepool Headland, UK. ICE Journal of Maritime Engineering. http://dx.doi.org/10.1680/jmaen.2016.28

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This forms part of Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Case Study CS-C5:

Sea walls: Vertipools, artificial seashore habitats

Summary

Seawalls are usually seen only as flood alleviation structures rather than as having other possible functions to benefit the wider environment. Where new walls are being installed there is opportunity to include more sympathetic "nature friendly" textured finishes to improve or maintain biodiversity. Where seawalls are already installed, retrofit enhancement measures provide significant opportunities.

Benefit: Medium

Engineering: Low

Ecosystem: Medium - High

Costs: Low

How does it work?

Vertipools are cast marine concrete units designed to be attached to sea defences to retain water as the tide recedes – they are shaped to replicate a range of natural microhabitats (e.g. rock pools) for shoreline species and are simply fixed with bolts or brackets and nontoxic waterproofing resin. They are durable enough to resist wave and tidal action for > 3 years in moderately exposed and exposed settings. The manufacturers are exploring a range of applications, across the full tidal range from beach level to splash zone and to capture freshwater seepage above high tide and sediment in low energy systems near perched mudflats for worm fauna etc.The potential for them to improve asset resilience is also being explored.

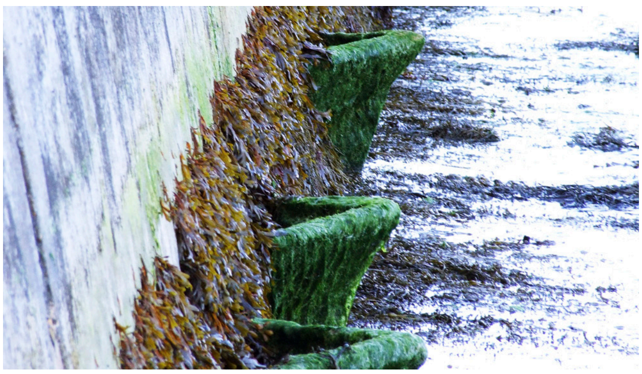
Motivation

To investigate how habitat can be retrofitted onto sea defences. The first two pump-priming projects were funded by community engagement; working with disadvantaged children and young people. Additional seed corn funding, along with monitoring by the University of Bournemouth, enabled a robust evidence base to be built. Vertipools have also now been deployed as part of environmental mitigation and enhancement requirements for ferry infrastructure and road works on the Isle of Wight, and as part of a NERC-funded public engagement project in Edinburgh.

Design innovation / Enhancement measure

Retrofit habitats are provided by retro-fitting prefabricated 3-D concrete units. The current pool designs are tetrahedral shaped cast concrete units with a robust 'prow' for deflecting wave energy. They are fixed in place with simple coach bolts and resin, or a plate. They are designed to provide important water-holding habitat and increase physical heterogeneity of otherwise smooth, homogenous vertical intertidal coastal defences.

To optimise ecological function, it is recommended they be fitted in groups of 5 with around 10 metres between groups. In this way, they provide pockets of high-density habitat along the length of the seawall. A 100m seawall would therefore require 50 Vertipools. Placement at around MLWN may have greatest potential for ecological gains, although future sea level can be considered.

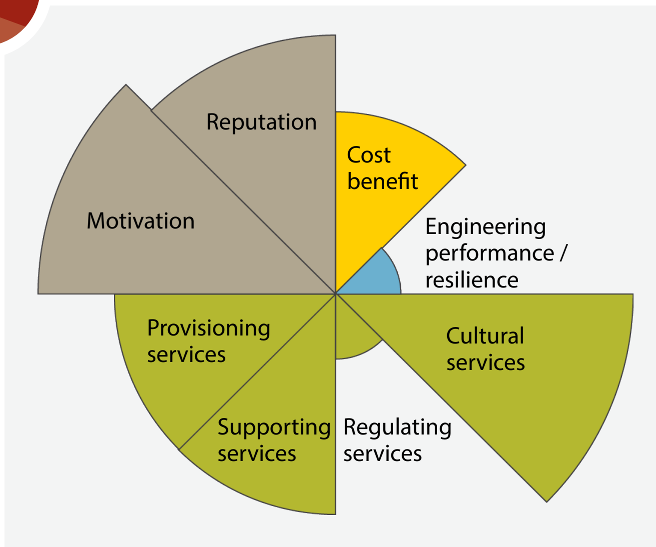


Benefits

Net cost benefits are expected to be low to medium. The trial pool costs are initially relatively high for the volume of habitat created, although the price is predicted to come down with economies of scale. The average price relative to sea wall construction costs are around 5-15%.

Where the pools offer opportunities for community engagement and education, the cultural services may be deemed relatively high, or where they provide mitigation for an otherwise less favoured development they could be considered to improve a schemes reputation.

Initial research shows the units provide some capacity for biodiversity enhancement.



Net Cost

Vertipools might be considered to have a relatively low net cost where the value in providing them is clear, such as:

- in certain planning and permitting circumstances e.g. offsetting habitat loss where new defences are installed and greener infrastructure options are ruled out.
- in engaging the wider public in the processes, the underlying science and the local natural environment (e.g. providing an educational resource - practicals, working with groups of young offenders, etc.).
- in retrofitting to provide habitat for biodiversity, therefore improving climate change resilience, or habitat for commercially significant and/or migratory species).

Direct cost of intervention

Vertipool costs depend on a number of factors including site assessment, planning and design. Installation requires some local and specialist knowledge (an understanding of site characteristics, ecology, substrate and fixings).

Pools can be made on site (and could include a community engagement element) or made and shipped for installation by contractors.

For the case study presented here, the site assessment, planning and design (including installation guide) was approximately £5000. Community engagement costs (including team of 4 practitioners, materials and resources) are estimated at £1000 for a 2 hour ‘drop in’ public consultation session, £2500 for a 4 hr participatory consultation and engagement event, to £3500 for a full day school workshop.

Cost compared to business-as-usual

The costs (after on-going trials are completed and with economy of scale) of 50 Vertipools for 100 m of seawall are estimated at approximately £300 per m (a cluster of 5 pools for every 10 m = 50 pools over 100 m); or £200 per m for 1000 pools to cover 2 km. Although the pools have so far been fitted as retrofit enhancement there are plans to include them on new developments. The costs are a relatively small percentage of the cost of new-build sea wall.

Examples of sea wall costs by type and size (EA, 2010 figures).

	Height	Cost per metre
Raise an existing wall with concrete and stone cladding both sides	1m	£1500 (over 100m)
Sea defence	3.8m	£2000 (over 1200m)
Reinforced concrete wave return wall	2m	£6300 (over 75m)

These figures show significant variation. The cost per metre of seawall installation can depend on source, type, availability and quality of materials, access constraints and weather, as well as the size (length, height and depth) of the wall. Based on these available costs, including Vertipools would increase costs by between 5% and 20% of the cost of raising or building a seawall.

Thus, the cost to an existing seawall being raised 1m over a 100m length would be:

£1800 per metre for one being retrofitted with vertipools compared to £1500 without.

To build a new 2m high reinforced concrete wave return wall it would be:

£6600 with or
£6300 without Vertipools.

There may be further cost savings from including these or similar habitats, including reducing the costs of managing non-native (e.g. Wire weed, *Sargassum muticum*) and invasive species that can dominate ordinary seawalls.

Long-term cost

It is not anticipated that the wall sections with vertipools or the vertipools themselves will require any additional maintenance or repairs compared to business-as-usual, so no additional direct costs are expected.

In addition to the points above, the long-term benefits could be important under some circumstances, for example, where the pools facilitate long-term community involvement in the natural environment – engaging and informing the public to foster long term support in decision making and stewardship.

Long-term savings may accrue in areas where Vertipools or similar inhibit the impact of invasive or non-native species, and where they facilitate climate change resilience through supporting biodiverse ecosystems.

Engineering performance, inspection and maintenance

Vertipools are designed to have no detrimental effect on the engineering performance of the defences, and trials show they can be applied and removed without compromising the structure, and any holes can be safely filled with cementitious material. Their ability to improve asset resilience is under study. No detrimental effects have been found since the first pools were installed in 2013 (3+ years) and the Vertipools have not affected inspection of the seawalls. At some sites sedimentation around pools appears to have increased natural armouring, though their role in sediment accumulation, buffering and improving asset resilience requires further assessment.

They are designed to be installed at a density that would not restrict inspections (see the recommended operational spacing detailed above) and are of a size that would not affect standard maintenance practices.

As the Vertipools are relatively small but pronounced structures, they are unsuitable for places where there is boat traffic and these protrusions need to be factored into detailed designs. Initial trials explored a range of shapes and sizes and ongoing monitoring data may produce options to suit the individual aims and objectives of specific installations.

Ecosystem services

Vertipools, or similar, offer an opportunity to retrofit habitat where currently there is little or none, increasing service provision from a low baseline. On-going assessments show significant colonisation in the pools – both in abundance and diversity – compared to the baseline conditions. After 3 years, the artificial pools increased species diversity on the seawall and attracted mobile fauna previously absent, including fish and crabs. Compared to 8 species recorded on the seawall, 16 species were recorded in the Vertipools including fish (Lipophrys pholis), shore crabs (*Carcinus maenas*), and gastropods (*Patella vulgata* and *Littorina obtusata*). Juvenile and adult life-stages of a range of species were found in the pools.

There is potential to adapt the pools to mimic specific habitat for individual species or target communities more closely. This could provide habitat for migratory species or native species colonising new areas under the effects of climate change, e.g. some anemone species and the rock pool Shanny. Where coastal squeeze becomes significant it is probable that Vertipools would become accessible to species currently surviving in natural pools at lower tidal levels.

Vertipools are designed to provide refuge for a variety of species, including commercially significant species including the edible periwinkle (*Littorina littorea*), edible mussel (M*ytilus edulis*), edible shore crab (*Cancer pagurus*) and the velvet swimming crab (*Necora puber*). Other species which may use the pools when submerged, for refugee and foraging, include intertidal crabs (*Pagurus bernhardus*) and fish (Gobies, Blennies, juvenile commercial fish like Wrasse and Bass). By attracting a range of species, the pools are thought to generate a 'reef halo' effect where nearby biodiversity also increases. This is being explored in 2017 using submerged cameras.

Further study is required to determine how well Vertipools can limit colonisation by non-native and invasive species in other areas. These species can negatively influence the native ecosystems, and visual amenity, and the costs in managing the impact can be considerable and chronic. Other trial pools quickly attracted a non-native sea squirt that was not previously recorded at that location, and the possibility of using the pools to track and act as an early-warning beacon for non-native and invasive species is being explored.

Social value

Young people have been involved in the design and manufacturing stages in some of the installations. The pools at Boscombe are accessible and, along with interpretation boards at the nearby Coastal Activity Centre and Aquarium, they will be incorporated into a Council nature trail and bio-beach attraction.

They have proved successful in engaging the public and University Students, approximately 100 people aged between 8 and 60 at making sessions (sand casting techniques and texture work) – a combination of Royal Society STEM work with Sandown Bay Academy (£5K school fund), Artswork/Hants police project (£5K budget), outreach and engagement work with young people not in education, employment or training (NEETS) and others, including vulnerable young adults in supported accommodation via a housing association.

In addition to the Vertipools providing habitat for commercial and recreationally significant species they are accessible at low tide and provide opportunities to investigate rock pool flora and fauna that are otherwise absent on stretches of heavily engineered coastlines; anecdotally the researchers feel the public appear to have enjoyed exploring these. A 'science beach' has been set up for such installations in The Bay area on the east of the Isle of Wight, a coastal resort receiving up to 500,000 visits a year. The strong design element to Vertipool appearance adds a sculptural quality to public space and this can be emphasised where public art commissioning is project objective.

Who can you apply this intervention/ technique?

Anyone looking to retrofit an established flat sea defence structure, where no alternative working with natural processes or green infrastructure solution is viable.

The vertipools can be deployed at any tidal height in the intertidal zone, and thus far have been successfully tested on moderately exposed to exposed open, non-muddy coasts in SE England.

Scaling up the benefits

The ecological benefits of fitting Vertipools where there is little or no habitat (i.e. on large expanses of vertical concrete) is large. These and other similar structures have the capacity to provide habitat where previously there was little or none, and could support locally significant populations. They can provide habitat in new developments where more conventional green infrastructure options are not possible.

The Vertipools installed thus far are relatively small individual pools, alternative designs could include an array of longer, vertically self-supporting pools in series, providing a range of habitats and benefits up the water column and tidal range. Repairs or new sea walls can be further optimised using a combination of IGGI measures such as textured walls (AP-C7 and AP-C8) and adding habitat features such as Vertipools.

The British coast has extensive hard defences, current pool designs hold 3.5 – 10 litres of water per pool, hence 5 pool clusters provide approximately 17.5 - 50 litres, and each pool provides an approximate surface area of around 0.15m^2 inside and 0.7m^2 outside of rock pool habitat.

The most suitable place for applying this measure is where artificial hard structures either replace or are adjacent to existing rocky shore habitats. In locations where other intertidal substrates underpin the natural habitat, it is important to evaluate whether adding rocky shore habitats will lead to improved ecological outcomes.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
ECONOMIC			●			●	
ENGINEERING			●	●			
ECOSYSTEM SERVICES			●	●		●	

Further information

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Case Study CS-C6:

Sea walls: habitat enhancement of replacement walls

Summary

The Elliott Bay Seawall Project in Seattle, USA, incorporates a number of biophilic measures included a textured sea wall with habitat benches, substrate enhancements (beach and marine mattresses), an intertidal corridor, and the transparent material in both the cantilevered deck (new build) and the piers (retrofit) to improve the amount of natural light reaching the shore.

Benefit	High
Engineering	Medium
Ecosystem	High
Costs	Medium

How does it work?

Generations of urban development extended the influence of the city into the bay, impacting on the plants and animals there. Buildings, piers and walkways were built close to and over the water. During sea defence reconstruction the developers integrated several enhancements into the design to improve habitat conditions for native species. These were based on earlier research undertaken by the University of Washington.

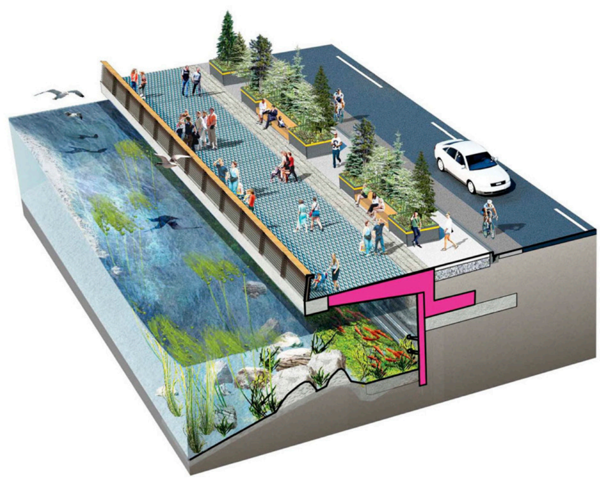
Motivation

The existing sea wall, built between 1911 and 1936, had deteriorated from significant seismic activity and damage from wood ingesting crustaceans (Gribbles). This made the wall unsafe and its ability to withstand future storm and/or seismic events was compromised. Repair and re-development of the near-shore area gave the opportunity to restore habitats lost or negatively impacted by long-term urbanisation, including salmon migration corridors and general improvements to ecosystem productivity.

Elliott Bay is an important juvenile salmon migration route (Duwamish River to the Pacific Ocean). However, shallow-water habitat is limited here, making migration along the shoreline difficult. Over-water structures also produced intermittent dark and light areas that are problematic for small fish to negotiate. A key driver of the scheme was to improve the degraded nearshore habitat for salmon.

Design Innovation / Enhancement measure

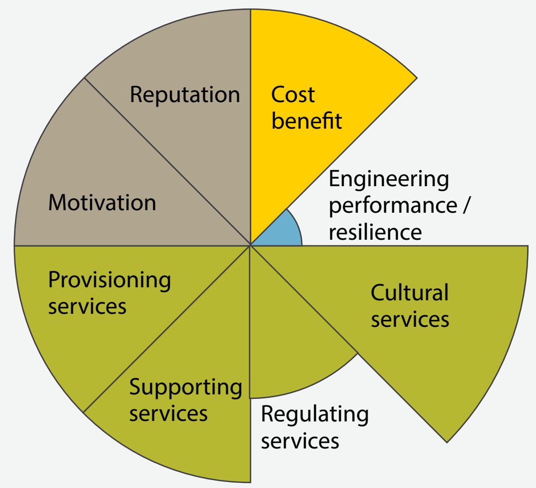
A range of eco-enhancements were used. Most notably, light-permeable materials (glass blocks and grated walkways) aim to reduce shading of the water column by large overwater structures that can affect feeding ability by juvenile salmon. Decades of development and dredging had removed all natural sediments, so some substrate enhancement measures were included to support plant and invertebrate colonisation. Artificial intertidal zones (habitat benches) and marine mattresses (sediment-filled mesh pockets placed at the bottom of the seawalls) were added to create additional protective shallow waters, in place of deep water. The seawalls themselves were also cast using textured formwork that was optimised for ecology and aesthetics.



Benefits

Much of the sea defence work and habitat enhancements were recently completed and the monitoring program has not yet begun. Anticipated benefits include: significantly improved amenity value for the local community alongside improved coastal protection by replacing existing assets in poor condition; enhanced waterfront habitat particularly for salmon; significantly strengthened collaborations between numerous regulatory agencies, private firms, academia and the City of Seattle – this high-profile project has highlighted the potential and importance of ecological considerations in engineering design of major, large-scale infrastructure/re-development works.

These designs were based on robust scientific trials carried out by the University of Washington. They tested designs for ecological enhanced concrete compared to smooth concrete sea walls, to see if this led to improved outcomes for species, including commercially and culturally important fish. They found that textured wall panels with areas of relief (and steps) supported more diverse communities than existing seawalls or the control (flat) panels.



Net cost

$410 million

Direct cost of intervention

Estimated to be $20 million (around 5% of the total project cost)

Cost compared to business-as-usual

Costs of the enhancements (approximately $20 million) were additional to the business-as-usual costs.

Long-term cost

Maintenance costs are unknown but they are not expected to have any impact on engineering performance or inspection routines. Post-construction monitoring of enhancement effects on local ecology is expected to cost an additional $1M to $2M over business-as-usual monitoring, over a 10-year period.

Engineering performance, inspection and maintenance

Specific measures included in the scheme were:
(1) creation of an artificial beach and placement of intertidal benches and stone-filled marine mattresses to create shallow water, low gradient habitat;
(2) incorporation of texture and relief into the seawall face to improve ecological potential within the intertidal and supratidal (accounting for future sea level rise), and;
(3) incorporation of light-penetrating surfaces in the sidewalk above the seawall toe to provide a light 'corridor' for juvenile salmon.

In this relatively sheltered, inland location these integrated green elements are expected to perform as well as any traditional/un-enhanced alternative. Compared to the assets being replaced, the scheme will have significantly improved engineering performance – the enhancement measures are not expected to affect performance or design life in any way. Inspection of the assets is unaffected by the enhancement design – access will not be restricted. On-going analysis of the performance of each element is planned.

Ecosystem services

Studies have not yet been conducted on the new seawall, as construction is still ongoing. Once seawall construction is complete, various elements will be monitored in the long-term. The physical characteristics of the habitat improvements, light penetration, invertebrate colonisation and salmon presence and behaviour will be reviewed. There is a plan to begin studies on light level impacts along the waterfront, including monitoring to determine the effectiveness at (i) creating an effective migratory corridor for juvenile salmonids and (ii) enhancing the marine nearshore ecosystem.

Research shows that migrating young Chinook salmon (Oncorhynchus tshawytscha), Chum salmon (O. keta) and Pink salmon (O. gorbuscha) avoid shaded areas, like those under docks and piers. In addition, they are negatively impacted by reduced availability of food sources in urbanised inshore areas. The scheme is designed to maximise habitat quality for these species by incorporating novel, low shade-casting structures over the water.

The health of the natural environment, natural history, fish, seafood and in particular the vitality of the native salmon populations appear to be very important to the current and historic identity of areas like Seattle.

The overt attempt to improve the urban marine environment visibly provides opportunities for the public to engage in the natural environment and conservation.

There is limited information on how well the new sea walls are performing ecologically, but if successful across the whole scheme, the following services are expected, though some may be relatively small scale: increased primary production, nutrient cycling and increased carbon uptake; natural sedimentation of biogenic material will increase carbon sequestration (therefore improving capacity for climate regulation); improved local biodiversity may increase potential to both decompose and detoxify local pollution (e.g. contaminated urban run-off); enhanced fish populations (both locally and wider commercial fisheries); enhanced social amenity value and public engagement with the waterfront environment, and improved awareness of ecological conservation at the coast.

Social value

Community engagement, commercial opportunities and sustainable infrastructure stability will all be improved by the holistic approach to regeneration of the area.

Who can apply this intervention / technique?

Anyone undertaking a project that involves development over water bodies can review similar alternative technologies and methods of incorporating novel techniques that reduce the impact on light levels through the water column.

Scaling up the benefits

Further research is required to assess the potential to apply the kinds of techniques used in this scheme elsewhere. However, where redevelopment works are planned the approach adopted in Seattle could be applied in many different contexts. Adopting ecologically sympathetic engineering designs more broadly will help maximise connectivity and biodiversity along heavily urbanised coastlines.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work.

DATA TYPE	DATA QUALITY / QUANTITY						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
COST	●						
ENGINEERING		●			●		
ECOSYSTEM SERVICES		●			●		

Further information / Contacts

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Prof. Jeff. Cordell: jcordell@uw.edu, https://wsg.washington.edu/research/integrating-intertidal-habitat-into-seattle-waterfront-seawalls-phase-2/

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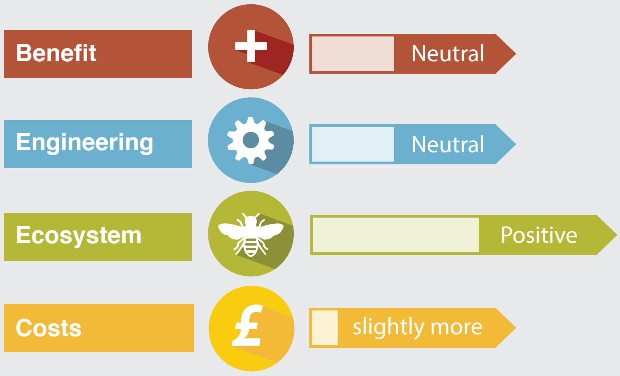
URL: waterfrontseattle.org/seawall

Case Study CS-C7:

Habitat enhancement of stone clad sea walls

Summary

Seawalls are usually seen only as flood alleviation structures rather than as having other possible functions to benefit the wider environment. Where new walls are being installed there is opportunity to include more sympathetic “nature friendly” textured finishes to improve or maintain biodiversity. Where seawalls are already installed, retrofit enhancement measures provide significant opportunities.



How does it work?

Small alterations were made to the mortar pointing between decorative stone cladding of a section of vertical concrete wall during construction of the Shaldon and Ringmore Tidal Defence Scheme. Based on evidence from existing scientific studies, niche habitats (grooves, holes and mini-pools) were created during construction to provide cool/moist refuge for intertidal wildlife at low tide, at three different heights on the wall. Ecological use of these features was compared with adjacent sections of unmodified wall.

Motivation

Primarily EIA Directive and Planning Conditions; mitigation for loss of foreshore habitat and potential coastal squeeze resulting from sea level rise. It was also important for this scheme to achieve an attractive structure with minimal negative visual impact on the surrounding historic conservation area.

Design Innovation / Enhancement measure

The intervention aimed to include habitat for target intertidal ecological communities via modifying an existing engineering design of an otherwise relatively homogeneous seawall. Niche habitats were incorporated into the fabric of a wall during the restoration/partial replacement of a sea defence. The measure used existing scientific evidence to inform the enhancement designs.

Three types of niche habitat were used, all achieved by leaving out occasional facing stones and filling with modified mortar (undertaken by the contractor) at the time of construction. First, grooves were scraped into the mortar based on existing evidence that small-scale (millimetre) grooves attract barnacles. Second, holes a few centimetres wide and deep were made by pushing a wood baton into the mortar. This was based on evidence that these kinds of holes are effective at supporting some species including limpets. Thirdly, small pools were created by placing a sand-filled bag into the recess created by leaving out a cladding stone. Mortar was slightly built up around this to create a lip (to retain water) and the bag was removed once mortar had cured.

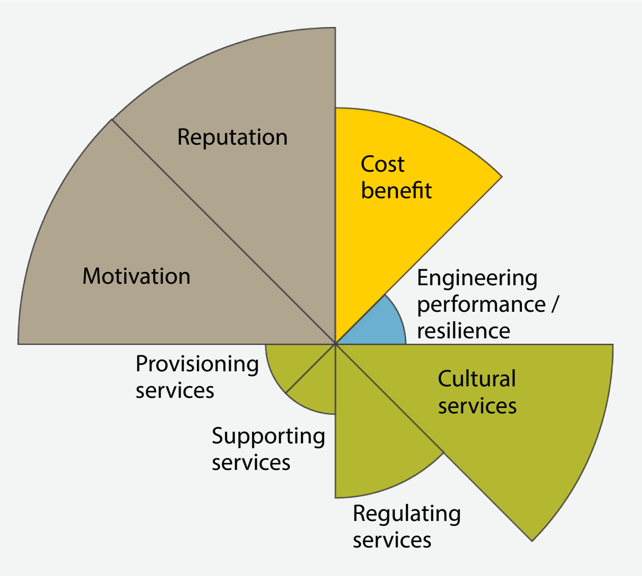
These different approaches were arranged at three different heights towards the base of the wall (the intertidal portion around MHWN), using a spacing that could provide robust scientific evidence during the monitoring period.

Benefits

The scheme was driven by a need to repair the existing sea defence in a sympathetic and visually acceptable way (within a historic conservation area) and to examine the potential to include ecosystem enhancement techniques. The research shows that it these small-scale enhancements are valuable in including habitat where there would be little or none if traditional methods were used.

Historic England has led much work in the UK on the economic values of historic sites, (cultural, aesthetic, educational value) but as yet there is little data on ecological enhancement values. The habitats here are relatively small but the positive results indicate significant benefits may be possible, e.g. for current or future priority species.

To this end the scheme achieved the goal of demonstrating the capacity for habitat to be built into hard, engineering-centric structures, and illustrates the potential for these schemes to provide ecosystem enhancements. The benefits from these greener approaches could be scaled-up to incorporate more habitat. Similar adapted niche habitats might provide interesting features on other restoration projects.



Net Cost

Scale, access and design all impact on the cost of sea defences. The structure here was local stone, and mortar cladding which covered a concrete wall that provides the coastal defence. Cladding of the concrete wall was required as the protection scheme was being build in a historic conservation area. This cladding was designed to provide ecological enhancements. The overall scheme cost around £8.3M in 2010.

Direct cost of intervention

Three direct costs were involved:

1. design and academic consultation = £6,520
2. construction costs = £1,000
3. monitoring for 18 months = £12,450

These costs represented less than 0.25% of the total scheme cost (£8.3M). Importantly, the additional design and construction costs were less than 1/2 of the total costs of the enhancement. Minimal training of contractors was required (< 1 day) to undertake the enhanced construction compared to business as usual. Widespread application of these ideas in future schemes therefore represents a very small additional cost compared to business as usual.

Cost compared to business as usual

The design and use of the niche enhancements had no bearing on the final approved design and construction for the scheme. A business-as-usual scenario (replacing the wall without including enhancement) would be have been £20,000 cheaper overall, but would not have provided any of the benefits identified below.

Long-term cost

Inclusion of the enhancements is not associated with any increased cost in the long term. Monitoring of the modified materials indicated no increase in biological deterioration of the construction materials.

Engineering performance, inspection and maintenance

This form of enhancement has no effect on inspection and maintenance regimes. The incorporated niche habitats do not obstruct or interfere with inspection in any way. Detailed monitoring has shown no negative effects on material integrity associated with the niche habitats. Engineering performance and design life are not affected.

In this scheme the stone cladding was a feature in front of the main structural defence, so the engineering impacts of these enhancements on the structural integrity of the scheme were negligible. All enhancement designs were approved by the overseeing engineer, prior to construction.

Ecosystem services

After a period of 18 months post-construction, nine invertebrate species were found in association with the enhancements. Grazing species (snails) were most commonly found in the holes and pools habitats, which retained water at low tide. The pool habitat supported significantly more species than adjacent, smoother sections of wall after this period, including snails, barnacles and algae. Overall, inclusion of the enhancement led to a greater abundance and diversity of species compared to comparable sections of wall without enhancements.

The enhanced wall is to a small degree successfully functioning as an intertidal habitat, helping support local biodiversity, and compensating for some loss of foreshore (approximately 1m) due to the footprint of wall. While no biological products are harvested from this initiative, part of our design was based on the success of similar interventions in increasing the abundance of a commercially important mollusc (Martins et al. 2010). The site is also close to a cultural and recreational centre and provides opportunities for engagement in the natural and historic environment.

Social value

As yet no data are available for social value. The niche enhancements are visible and accessible at low tide, and may offer some amenity/educational value. The local stone cladding used for facing the wall (of which the mortar joints were enhanced) was specifically chosen to be in-keeping with the surrounding historic landscape.

Who can apply this intervention / technique?

The simple modifications to the wall at Shaldon could be applied to any similar scheme, and could be adapted to suit different types/construction of hard defences. The main limitation in providing habitat enhancements for intertidal species is position of the structure with the tidal frame – which must be low enough to ensure surfaces are below tide for at least part of the day. At Shaldon the wall enhancements had to be positioned around MHWN. Water retaining features and textured surfaces can mitigate desiccation stress higher within the tidal frame (where time of exposure at low tide is greatest), but greater diversity of species may be achieved in association with enhancements placed lower in the intertidal zone.

Some consideration is required for the possibility of recessed habitat niche habitats becoming silted up over time. Whether, and how quickly, this occurs will depend on local water and sediment conditions.

Scaling up the benefits

Similar enhancements could be used across whole defence schemes at little additional cost (~ 0.5% or £100 per metre). The approach adopted here of incorporating small niche habitat features (holes, pools and texture) during the construction, will work best for blockwork/masonry constructions that incorporate mortar. Mortar is easily manipulated prior to curing.

The scale of application of this kind of enhancement at Shaldon was limited, acting primarily as a proof-of-concept for applying academic research to operational structures. Application of these techniques to entire schemes, or multiple schemes along a coastline, would help support local and regional-scale biodiversity, particularly in light of habitat losses from necessary coastal protection works and coastal squeeze.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

Expert Judgment
interpretation of the scheme by one or more experts

Wider Supporting Evidence
extrapolated from published work or reports by practitioners.

DATA TYPE	DATA QUALITY / QUANTITY						
	Scheme specific information			Expert judgement		Wider supporting evidence	
	No Data	Limited reported sources	Strong reported sources	Some expert opinion	Multiple experts	Some sources	Multiple sources
COST			●	●			
ENGINEERING			●				
ECOSYSTEM SERVICES			●		●		●

Further information / Contacts

Best practice case study:
www.ecrr.org/Portals/27/Shaldon%20Intertidal%20Habitat%20Enhancement.pdf

Coombes, MA. et al. (2015). Getting into the groove: Opportunities to enhance the ecological value of hard coastal infrastructure using fine-scale surface texture. Ecological Engineering 77, 314-323. https://doi.org/10.1016/j.ecoleng.2015.01.032

Coombes, MA, Naylor, LA, Jackson, AC, Thompson, RC. (2012). Shaldon and Ringmore Tidal Defence Scheme: Ecological Enhancement Monitoring Report (18 months post-construction). Report to the UK Environment Agency, University of Exeter and University of Plymouth, UK.

Firth, LB. et al. (2014). Between a rock and a hard place. Coastal Engineering 87, 122-135. http://dx.doi.org/10.1016/j.coastaleng.2013.10.015

Martins, GM. et al. (2010). Enhancing stocks of the exploited limpet Patella candei d'Orbigny via modifications in coastal engineering. Biological Conservation 143, 203-211. https://doi.org/10.1016/j.biocon.2009.10.004

Naylor, LA. et al. (2012). Facilitating ecological enhancement of coastal infrastructure. Environmental Science and Policy 22, 36-46. http://dx.doi.org/10.1016/j.envsci.2012.05.002

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Prof. Richard Thompson: r.c.thompson@plymouth.ac.uk

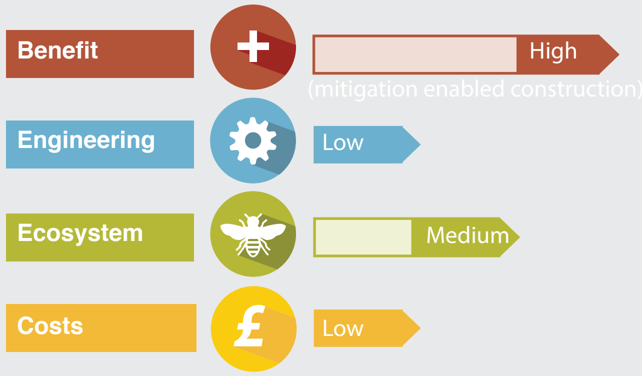
This forms part of Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

Case Study CS-C8:

Intertidal habitat created around a new development

Summary

The plan to expand the Vancouver Convention Centre took the new building out, seaward across 50 m of coastline and 140 m^2 of marine habitat. Before the federal Fisheries and Oceans Canada authorised this development they stipulated that loss of marine habitat had to be compensated for. An on-site mitigation plan was approved and construction was completed in 2009. Three enhancements were built including a series of stepped, pre-cast, concrete "benches" were attached to, and extended out from, the perimeter of the structure (both buildings and the promenade), around the west, north, and east aspects. The benches provide habitat connectivity to the existing shoreline, allowing safer passage of salmonids through the development.



How does it work?

The intertidal mitigation includes three measures: a habitat skirt, feature rocky intertidal habitats and the use of glass blocks on the promenade to allow natural light onto the intertidal and subtidal communities. This was complemented by creation of subtidal marine habitat; this case study focuses on the intertidal habitat elements. Collectively, these features were designed to optimise the potential for a diverse range of marine habitats and species that would colonise the site.

For the habitat skirt, the three shore-facing perimeter faces of the marine foundation were fitted with 500 metres of bioengineered intertidal habitat skirt structure, consisting of a series of stepped, precast concrete benches supported by precast concrete frames attached to a specially designed cast-in-place perimeter concrete beam.

The concrete stepped "bench" design increases surface area and retains moisture during low tide conditions. Several features were added to the top surface of the benches to promote marine growth; a continuous depression, or trough that mimic rock pools by retaining water when the tide recedes, and exposed aggregate on the top surface to increase the variability of the surface texture and elevation to create habitat features. The other intertidal habitat features are described below.

Motivation

The aims were to maximise vertical and horizontal ecological connectivity to create habitats for a diverse mix of intertidal marine life. On site ecological mitigation was required as part of a federal and city level initiative to provide a continuous habitat corridor and protect from predators for salmonids. It aimed to promote the growth of marine organisms that support the higher food chain and be robust enough to withstand the harsh marine environment over the lifespan of the building, including wind and vessel generated wave loading, floating debris impact and salt-water corrosion.

The high profile nature of the site (i.e. an iconic development) meant that the ecological enhancements had to complement the architectural design.

Design innovation / Enhancement measure

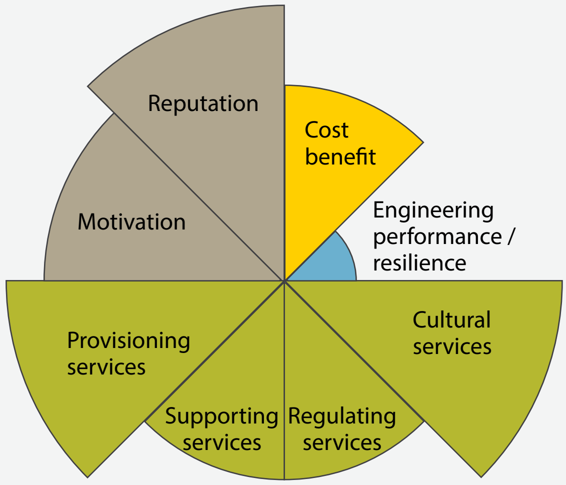
The habitat skirt includes 362 precast slats that were fitted into 76 frames, creating a large 5-tiered staircase structure that is 477 m long and provides 6,122 m^2 of surface area. The horizontal surfaces and sloped vertical edge of the habitat skirt mimic the replaced gradual slope and re-establish coastal marine habitat for many invertebrates that support predatory species such as sea otters, and provide connectivity with the existing coastline for migrating juvenile fish, specifically salmon.

Benefits

The cost of the ecosystem enhancement can be considered intrinsic to the project, as on site mitigation was required for encroaching over the intertidal area. The engineering performance has not been compromised, although unexpectedly high colonisation was an initial concern to engineering performance post-construction, but engineering performance has not been adversely impacted (9 years post-construction).

Through providing mitigation for the building of the Convention Centre (and the associated cultural and economic benefits) and in the habitat enhancement for native and iconic species such as sea otters and salmon, the skirt provides important cultural, supporting and provisioning services.

The improved habitat sequesters more carbon than a business-as-usual alternative through enhancing levels of primary production (and nutrient recycling).



Net Cost

Whole construction project = $CDN 615 Million.

Direct cost of intervention

The Convention Centre cost $CDN 615 Million, of which $CDN 20 Million was related to the marine ecological mitigation components. This comprised $CDN 8.3 Million for the habitat skirt and the remaining $CDN 11.7 Million was the cost of the structural components (bigger concrete beams, more piles) required to support the habitat skirt.

Cost compared to business-as-usual

This equates to a ~3% increase in total construction costs for the entire scheme. If off site mitigation were possible, this would have cost on the order of $CDN 3 Million to purchase and enhance compensatory habitat, less than 0.5% of the total project budget. However, as the scheme's design caused substantive habitat loss and damage to a protected marine ecosystem, planning permission would have been impossible without the on site mitigation in this case study.

Long-term cost

No data is available as the scheme is less than 10 years old.

Engineering performance, inspection and maintenance

A scientific advisory panel advised the Consultant on an ecological design that met engineering and habitat requirements and was approved by the regulator (The Fisheries and Oceans, Canada). The engineering design was modified to incorporate the habitat skirt.

The engineering performance has not been affected to date (8 years post-installation); the additional load of unexpectedly high colonisation was an initial concern post-construction but this has not impacted on engineering performance.


Photo Credit: Advisian

Ecosystem services

The habitat skirt did not replicate the pre-existing conditions precisely (e.g. for current and light exposure) but species' population similarity was greater than 65%. The bare substrates behaved similarly to the control. While the hard substrates could be expected to colonize in 2 to 4 years, minor microhabitat and elevation differences led to different ecological outcomes between sites; generally species richness decreased with elevation, linked to greatest species recruit in association with vertical connectivity with the sea floor. Species richness was greatest in pools around MLWN to MHWN and on vertical habitats at around MLWS.

Although a working harbour with a high potential for invasive species, this was not found to be an issue.

At the right tidal height, the skirt provides refugia and nurseries for juvenile crabs and other species leading to niche expansion from the presence of tide pools. Economically relevant species include dungeness crab, blue mussels and juvenile salmon. Estuarine conditions are particularly important to salmon development. Feeding opportunities can be relatively high and predation pressures low, particularly where high turbidity and estuarine and riparian vegetation provide cover. Around half of the Sockeye and pink salmon populations locally are harvested commercially (around 1 million Sockeye and 1.5 million pink) across the USA Canada border area. These and other species support extensive commercial, recreational and First Nation food, as well as social and ceremonial fisheries.

Increased primary production, most significantly by macro-algae and kelps, and subsequent increased biological activity up the food chain, will also increase nutrient recycling locally.

Social value

The skirt is not a physical recreational resource and cannot be accessed directly, though it does form the basis of a number of activities – as an exemplar at international conferences and other knowledge sharing events, including activities with graduate students locally. The provisioning services it provides are also the source of important cultural heritage and recreational benefit for society in the region.

Reputation

The Convention Centre has been granted LEED platinum-level certification, partly for the innovative marine habitat mitigation measures. It is thought to be the only convention centre with this designation making it a world-leading design concept. The centre also won the Professional Convention Management Association's (PCMA) Environmental Leadership Award (2010).

Who can apply this intervention / technique?

Any developer or government agency that is responsible for the design or approval of coastal infrastructure that impacts on the coastal and marine environment. Whilst these measures were done as part of required mitigation, they also could be used to ensure net gain, reduce risks of coastal squeeze for habitats under a changing climate and demonstrate corporate social responsibility.

Scaling up the benefits

The Convention Centre was a relatively large-scale project that created a shadow over around 140 m2 of sea floor, damaging the ecosystem beneath it. The combination of subtidal and intertidal habitat creation features has proven to successfully mitigate for the habitat loss and provide important ecosystem services. The principles in this scheme could be scaled up to whole estuary initiatives, or be used elsewhere for other habitat mitigation requirements at the scale of individual developments.
Other factors to consider when designing coastal ecological enhancements; the degree of wave exposure and water movement, temperature averages and extremes, light levels, methods of recruitment, stresses (limiting factors are generally considered to be inter-species and intra-species competition at lower levels, physical stresses higher up the tide). See the coastal business case for more detail on these factors.

Data Quality

The table shows the relative strengths of the Economic, Technical and Environmental data available. They are classified as:

Scheme Specific
part of a PhD or similar detailed research

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interpretation of the scheme by one or more experts

Wider Supporting Evidence
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COST			●		●		
ENGINEERING		●			●		
ECOSYSTEM SERVICES			●		●		

Further information / Contacts

Slogan, J.R. 2015. Evaluation of Design, Environmental, and Sustainability Attributes Affecting Urban Fisheries Restoration Habitat in Vancouver, British Columbia, Canada. Unpublished PhD Thesis, University of British Columbia.

URL: http://www.vancouverconventioncentre.com/about-us/environment

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Coastal Art of the Possible

Vegetated tidal mudflat creation

What is the measure?

Artificial mudflat habitat – sheet piling was removed and the replacement defence was set back by 6 meters with rip-rap toe to create a new mud flat habitat on the banks of tidal river Camel, Wadebridge, North Cornwall.

Primary driver

Replacement of the sheet pile was identified as essential for the protection of a housing development, as existing sheet piles were suffering from corrosion (accelerated low-water corrosion). There was an opportunity to set the new sheet pile wall further back, to create space within the tidal and fluvial channel to catch small amounts of intertidal sediment and create an artificial mudflat habitat.

Benefit

This solution had the additional benefits of habitat creation, sedimentation in addition to reduced inspection, maintenance and repair costs (reduced corrosion) which make the business case economically robust, particularly in the longer-term.

Cost

This investment relative to the rest of the private development is moderate.

Engineering

It was not possible to refurbish the existing piles as this would not have provided the 100 year design life that was agreed as part of the planning permission for the new residential development. To achieve the 100 year design life a replacement sheet piled wall was selected which required protection to minimise corrosion rates. By setting back the piles from the edge of the channel the lower section could be protected by using fill material and only the upper section needed to be protected using concrete cladding. Designed not to compromise performance, inspection or maintenance, new pile walls extend the lifespan of this section of defence. Subject to regular asset inspection.

Asset resilience

This option installs new piles to extend the life of the defence in this location.
Long-term benefits are Medium.

Ecosystem services

Small realignment of sheet piles gave the opportunity for a stone / rock toe to the defence. This was designed to catch estuary sediment and provide a small feeding zone for estuary birds. Set back defence also provides a wider channel to accommodate fluvial and tidal events. Benefits not measured.

Social

Sheet piles were clad with a cast in-situ concrete facing. The facing provides corrosion protection and a more attractive finish to raw sheet pile. A form liner was used to mimic vertical slate walls that are a traditional finish in the Camel Estuary and North Cornwall. Landscape and visual impact was considered during design. An initial design was to have a cantilevered walkway over the space though this was not delivered in final construction.

Reputation

Renovation and improvement of the local defences may have helped the developer when selling the houses although there is no data.

Policy

The replacement flood defence wall could not be installed further into the estuary due to the loss of habitat that this would cause. The setback defence resulted in a net increase in intertidal habitat and the residential development was designed to be adequately defended from coastal flood risk over its lifetime by using raised defences and elevating floor levels above the predicted flood levels for Wadebridge.

Further data

Contact:
James Burke / Frank Newell,
Environment Agency Bodmin Office, Cornwall, UK.

Art of the Possible

Bioblock

What is the measure?

Precast habitat-enhancement unit comprising multiple habitat types that can be used as part of intertidal rock armour coastal defence structure. One 5.4 tonne BIOBLOCK (1.5 m × 1.5 m × 1.1 m or 2.48 m^3) was deployed as part of a new rock groyne.

It was tested on a moderately exposed coast at Colwyn Bay, West Wales, UK, 2012.

Primary driver

To improve the habitat and ecological potential of hard engineered structures.

Benefit

Supporting ecosystem services were measured in this study. The pools supported higher diversity than neighbouring similar, exposed surfaces and where they were included the overall species diversity increased. There are clear ecological benefits from the prototype BIOBLOCK; Units could be adapted to encourage rock-pooling to enhance cultural benefits; the prototype cost of a single unit compared to BAU was expensive, however mass production would reduce costs and improve the benefits (ecological and cultural).

Cost

Per unit cost: £2000 for the mould, casting, transport and deployment of the prototype BIOBLOCK which is equivalent to £800/m3. This compares to between £63 – 93/m3 for rock groynes (EA 2015, 2010 prices). The bioblock is between 9 – 13 times more expensive per unit compared to business as usual rock armour units used in rock groynes. Mass production of the BIOBLOCKS would reduce their costs. Further details on costs can be found in Firth et al. 2014.

Engineering

Expert judgement by engineers assumed no impact on engineering function of the groyne rock revetment. A BIOBLOCK can replace any rock armour unit on a defence structure and should last >10 years.

Ecosystem services

The BIOBLOCK supported greater biodiversity than the surrounding rock revetment. The range of habitat types (rock pools, ledges, overhangs, pits) rather than any one particular habitat type drove this pattern.

Policy

Influenced by the Marine and Coastal Access (UK) Act 2009 and the UK Marine Policy Statement 2011 which states that developments should avoid harm to marine ecology and biodiversity and provide opportunities for "building-in beneficial features".

Further Data

Firth, LB et al. (2014). Between a rock and a hard place: environmental and engineering considerations when designing coastal defence structures. Coastal Engineering, 87: 122-135.

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Dr Louise Firth: louise.firth@plymouth.ac.uk
@Louise_Firth_IE

URL:
www.theseusproject.eu/
www.urbaneproject.org

Armour drill-cored rock pools

What is the measure?

A technique for increasing water-retaining features on horizontal or gently sloping substrates; it was tested by retrofitting sets of four 150 mm diameter holes at either 50 mm or 120 mm deep per rock armour unit using a core drill, between MLWS and MHWS, on a granite rock armoured breakwater in Tywyn, Wales.

Primary driver

To test efficacy of retrofitted water-retaining features in improving ecosystem enhancement.

Benefit

Supporting ecosystem services were measured in this study. The pools supported higher diversity than neighbouring similar, exposed surfaces and where they were included the overall species diversity increased; however, the unit cost makes them expensive compared to business as usual.

Cost

£2000 of labour for 4 days drilling to make 40 rock pools on existing rock armour. Four (150 mm diameter) holes were drilled per rock armour unit (assumed to be 1m^3), costing ~£200 per m^3. This compares to between £42 – 107/m^3 for rock armour (2010 prices, (EA, 2015)). Four pools per m^3 are between 2 to 5 times more expensive than business as usual per retrofitted unit. Cost per retrofitted pool was ~£50 but savings would be possible if pools were drilled prior to installation rather than as an on shore retrofit.

Engineering

The size and density of holes did not undermine the engineering performance, nor alter the inspection or maintenance regimes of the rock armour.

Ecosystem services

The pools supported higher biodiversity than surrounding surfaces without water-retaining features where the unaltered, exposed areas of the structure reached species saturation after 6 months. In comparison, after 30 months, more species were still arriving in the rock pools and saturation had not been reached. When compared to natural rock pools, the artificial pools supported a similar number of species; however, community structure differed.

Reputation

Awarded the 'Most Innovative' design at the 2014 CIRIA Big Challenge Awards and is included in CIRIA's 2015 Coastal and Marine Environmental Site Guide.

Policy

Influenced by the Marine and Coastal Access (UK) Act 2009 and the UK Marine Policy Statement 2011 which states that developments should avoid harm to marine ecology and biodiversity and provide opportunities for "building-in beneficial features".

Further data

Evans, A.J. et al. (2016). Drill-cored rock pools: an effective method of ecological enhancement on artificial structures. Marine & Freshwater Research 67: 123-130. doi.org/10.1071/MF14244

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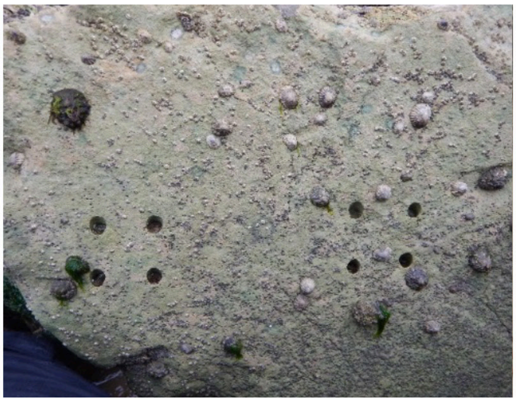
Art of the Possible

Armour pits and grooves

COASTAL

AP-C4


What is the measure?

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 created habitat features were tested at Runswick Bay, N. Yorks and Boscombe, Poole Bay, Dorset (both moderately exposed sandy shores).

Primary driver

To test the efficacy of increased surface heterogeneity and retrofitted water retaining features in improving ecosystem enhancements of rock armour.

Benefits

Improved ecological outcomes (increase in species diversity on granite) compared to business-as-usual were found after 12 months. Additional cost of adding the holes varied by material type but ranged from 15% to 100% more expensive than business-as-usual.

Costs

The cost of retrofitting holes into rock armour varied by material type. Limestone was less expensive to retrofit (£10/m³ or 4 hours for 48 boulders) than granite (£55/m³ or 2 hours to retrofit 12 boulders). This cost is then scaled up to m³ to compare it with standard Environment Agency rock armour prices for rock revetments. This equates to ~£17/m³ and £88/m³ in additional costs to add the enhancements onto limestone and granite, respectively. Standard rock armour for revetments costs between £42 – 107/m³. Adding drill holes to the granite rock armour would be approximately 1.2 to 2 times the business as usual costs for commercial rock armour. This means it would cost between £130 -£195/m³ for combined rock purchase and drilling costs. For limestone these costs would be lower, adding between 15-40% to the cost of business as usual rock armour, thus costing between £84-£150/m³.

Engineering

No discernible negative impact. The size and density of the holes were too small to adversely impact on the engineering performance of rock armour.

Ecosystem services

Both sites were monitored for 12 months where 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. This demonstrates that simple enhancement techniques can provide improved supporting ecosystem services (e.g. habitat provision). Other ecosystem services were not measured as part of this study.

Policy

No specific mitigation requirement; the habitat creation assisted approval of the Runswick Bay coastal defence scheme by the Marine Monitoring Organisation and Natural England, as it is within a Marine Conservation Zone.

Further Data

Hall et al. (2017). Improving habitat heterogeneity on coastal defence structures. ICE 2017 proceedings.

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Dr. Roger Herbert: RHerbert@bournemouth.ac.uk

Art of the Possible

Concrete rock pools

COASTAL

AP-C5

What is the measure?

Artificial concrete rock pools were created on a causeway in Galway Bay, Ireland (made of precast concrete hollow-core Shepherd Hill energy dissipation (SHED) units). The water-retaining features were made by pouring quick-drying concrete around buckets in the base of the SHED units. The buckets were removed when the concrete set, leaving 10-14 cm diameter and 10-12 cm deep depressions (~1250 cm^3 volume). In total, 80 pools were created: 20 in the upper (0.4 m above MHWS) and 20 in the lower (1.9 m below MHWS) shore on both the eastern (sheltered) and western (exposed) sides of the causeway.

Primary driver

To test efficacy of artificial concrete rock pools/water-retaining features in improving ecosystem enhancement at different shore heights in the tidal column.

Benefit

The trial pools proved successful in increasing biodiversity on the causeway, and illustrate how enhancements at different heights can provide a range of ecological responses over time. No studies were done on wider ecosystem service and engineering benefits.

Cost

Eighty pools cost approximately 3000 € (including labour, materials and equipment) extra beyond the normal grey engineering costs for the SHED units, the equivalent of 38 € per pool.

Engineering

inspection or maintenance of the SHED units. The City Council Engineer approved these enhancement design. Long term – the pools and SHED units survived the winter storms of 2014; storms with a 1% chance of occurrence annually.

Ecosystem services

After the initial 12 months the lower and exposed pools supported greater diversity than the upper and sheltered pools respectively. However, after 24 months, all sheltered pools became inundated with sediment, creating muddy habitats, while the lower exposed pools became colonised with greater total diversity than the upper exposed pools; showing that <20 exposed pools can improve biodiversity outcomes. For rare species, more pools would be required.

Reputation

Galway City Council provided advice and permission for the work and this research helps the city understand and promote their rich biodiversity (see: https://www.irishtimes.com/news/environment/a-rock-pool-for-life-to-cling-to-1.1405371).

Policy

Currently, there are no policy drivers in Ireland to promote this work. Similar projects in the UK are influenced by the Marine and Coastal Access (UK) Act 2009 and the UK Marine Policy Statement 2011 which states that developments should avoid harm to marine ecology and biodiversity and provide opportunities for "building-in beneficial features".

Further data.

Firth, LB., et al. (2016). Eco-engineered rock pools: a concrete solution to biodiversity loss and urban sprawl in the marine environment. Environmental Research Letters, 11(9), p.094015.

Contacts:
Louise Firth: louise.firth@plymouth.ac.uk
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Steve Hawkins: S.J.Hawkins@soton.ac.uk

This work was a collaboration by Plymouth University, Southampton University, Marine Biological Association of the UK and Galway-Mayo Institute of Technology.

Art of the Possible

Armour breakwater enhanced concrete

COASTAL

AP-C6

What is the measure?

Different design features were created through experimental modifications during the maintenance of concrete armour units fronting an existing detached breakwater in Plymouth Sound. New habitat was added by drilling 400 small water-retaining holes per concrete armour unit; each hole was 14mm or 22mm in diameter and 25mm long with a slight downward angle.

Primary driver

To introduce habitat (small water retaining pools, holes and surface roughness) in 100 tonnes cast concrete armour on breakwater. To demonstrate the influence of small modifications to concrete cast armour defence units on the diversity and abundance of local marine species.

Benefit

The results demonstrated that the productivity and biodiversity of hard, offshore breakwater structures can be improved by retrofitting habitat features into concrete armour units. Such an approach could be applied to other armour units made of either rock or concrete.

Cost

The armour units used on the breakwater are 42 m^3 truncated pyramids that are 3200 mm x 6850 mm at the base, 2430 mm x 5100 mm at the top, and 2350 mm high. Each unit was retrofitted with 400 holes by drilling. On average, it took 8 to 10 hrs, costing £60 - £75 m^2 (assuming an hourly rate of £30), or £240 to £300 per armour unit.

As part of routine maintenance, twelve – 15 new concrete armour units are added to the breakwater per year; the cost of these are unknown. Creating the enhancement via drillings adds an additional annual cost of ~£240 to £300 per unit. The Environment Agency's (2015) offshore breakwater armour cost per metre is between £1750 - £3304 (2007 prices). Adding 100 holes per m^2 would be a modest cost increase – between 2-4% per metre.

Engineering

These relatively very small modifications are not believed to have a detrimental impact on engineering performance, alter its resilience and/or weaken the structure in any way.

Ecosystem services

Breakwaters are generally seen as being of low habitat value, predominantly because they are topographically less complex than natural rocky shores (Firth et al. 2011). Adding surface complexity simply by drilling relatively small holes into the units adds habitat to these extensive coastal structures. However, colonization rates and outcomes for individual species can be difficult to predict and site-specific studies would be required to assess and plan modifications to encourage desired outcomes.

Social

While the enhancement area is not accessible to the public, the improved biodiversity can benefit society through improved habitat for species that support commercial or recreational marine activities.

Reputation

No specific reputation data were collected in this study. These techniques could be used in future schemes to address local planning, climate change or biodiversity issues.

Further Data

Juliette Jackson, 2014. The influence of engineering design considerations on species recruitment and succession on coastal defence structures. Plymouth University

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Textured concrete for biodiversity

What is the measure?

Millimetre-scale grooves applied manually using a wire brush to concrete during casting/curing designed to improve the rate of settlement and abundance of barnacles and associated species.

Tests were carried out on wave exposed, open coasts in Cornwall.

Primary driver

To test if we can improve the ecological potential of marine concrete infrastructure for early colonists (barnacles), compared with business as usual plain-cast concrete.

Benefit

Simple inexpensive additions (mm-scale grooves) to the manufacture process led to a 7-fold improvement in biodiversity compared to plain cast concrete after 3 years for limited additional cost. Barnacle colonisation was increased through texturing which has been shown to improve asset resilience (AP-C9).

Cost

Limited additional labour was required during casting (30 minutes per m^2) adding approximately £15/m^2 to the manufacturing cost, representing an increase of between 0.3% and 6.6% compared to BAU. EA figures for 2010 suggest a range between £0.5k and £5.5k per m^2 for sea wall defences. AP-C8 demonstrates that this scale of texture can be readily manufactured using textured formwork.

Engineering

Concrete panels are produced as normal with the only manufacturing change being adding striations with a wire brush. Structures colonised with organisms like barnacles will have no or negligible impact on engineering performance, service life or maintenance.

Asset resilience

Increased cover of barnacles has also been found to improve concrete and rock resilience to weathering-related deterioration in field and laboratory trials (AP-C9).

Ecosystem services

Only supporting ecosystem services were measured by this study. Results show that more than double the number of barnacles was found on grooved concrete than plain-cast concrete in < 6 months. Increasing barnacle abundance (via texturing) also increased invertebrate species richness (a 7:1 ratio) after 2 to 3 years.

Social

Textured concrete is often more aesthetically pleasing than smooth alternatives. Facilitating sedentary species like barnacles and seaweeds can also exclude less attractive, slippery ephemeral green algae and reduce disturbing maintenance works through increased asset resilience (AP-C9).

Policy

Can assist in meeting requirements to maximise ecological potential under the Water Framework Directive.

Further Data

Coombes, M.A., et al. (2015). Getting into the groove: Opportunities to enhance the ecological value of hard coastal infrastructure using fine-scale surface textures. Ecological Engineering 77: 314-323.

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This forms part of Naylor, LA., Kippen, H, Coombes, MA., et al. (2017). Greening the Grey: a framework for integrated green grey infrastructure (IGGI). University of Glasgow report. URL: http://eprints.gla.ac.uk/150672/

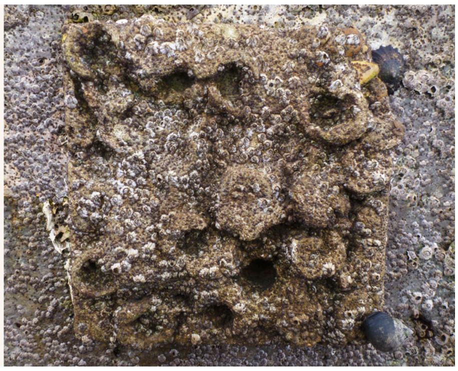
Art of the Possible

Textured concrete for sea walls

COASTAL

AP-C8





What is the measure?

Testing mm to cm scale surface texture designs to ecologically enhance vertical coastal structures (e.g. defences, walls, piers, pilings) compared with industry standard smooth plain-cast concrete. Eight different tile designs (184 tiles, 150 x 150 x 40 mm) were placed at mid to upper tidal level on north facing vertical seawalls at Saltcoats harbour, Scotland (sheltered), Blackness pier, Scotland (muddy, semi-exposed estuary) and on a sea wall on the Isle of Wight, England (moderately exposed). Tiles were cast in two material types: marine concrete and natural cement-based concrete.

Primary Driver

To establish the largest trial of ecologically enhanced text panel designs across the UK to determine which surface textures are optimal for enhancing species richness and diversity.

Benefit

Adding surface texture to concrete structures that are typically plain-cast by design increases the quantity and quality of habitat available for rocky intertidal species. The only additional cost for future applications would be the design and production of textured formwork.

Cost

For these prototypes, the cost of formwork design, production and deployment of 184 test tiles was approximately £8500. This equates to £33/m^2 for the initial production; however, the silicone formwork can be reused up to 20 times, reducing the costs to < £2/m^2. where the silicone moulds can be re-used at least 20 times reducing the cost per m^2. If commercially available textured form liners are used it would cost £8-30 per m^2 more than BAU. This is a small increase (0.1 - 0.6%) in cost based on suggested EA 2010 figures for sea wall of around £5,500 m^2.

Engineering

The test tiles did not compromise the engineering performance of the structure as they were affixed onto the existing surface using natural cement and/or marine epoxy; future integral, pre-cast design would not affect performance, inspection and/or maintenance.

Asset Resilience

Many of the tile designs attracted high abundances of barnacles in as little as 6 months post-installation (over one settlement season for barnacles). High barnacle abundance has been found to reduce weathering-related deterioration in field and laboratory trials (AP-C9); there is potential to use some of these designs in future formwork to improve asset resilience.

Ecosystem Services

Only supporting services were measured in this study. Ecologically enhanced tiles with greater habitat complexity hosted higher abundance and species richness than plain-cast counterparts after six months.

Policy

A further test of these tiles has helped deliver the Edinburgh Living Landscape's action plan.

Reputation

The trial at Saltcoats Harbour has assisted the local council in demonstrating they are exploring ways of enhancing the multifunctionality and ecosystem services of hard coastal structures to inform their shoreline management and coastal protection plans.

Further Data

MacArthur, M. et al. (2017). Ecologically Enhancing Coastal Infrastructure. Geophysical Research Abstracts Vol. 19, EGU2017-921-1.

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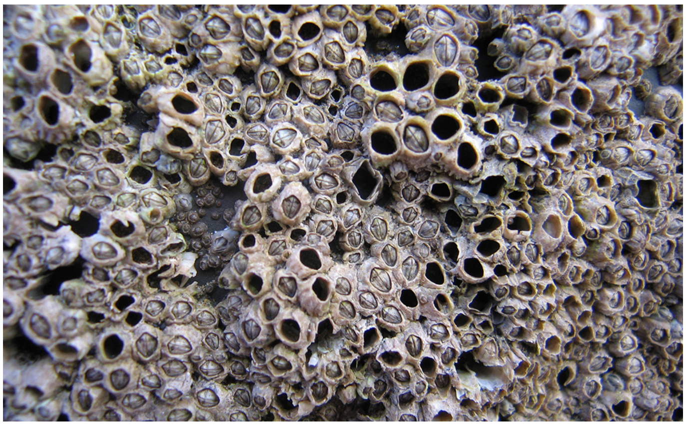
URL: meetingorganizer.copernicus.org/EGU2017/EGU2017-921-1.pdf

Art of the Possible

Bioprotection of engineering assets

COASTAL

AP-C9



What is the measure?

A cover of barnacles or seaweed buffers porous rock and concrete. Alongside ecological gain, encouraging colonisation can improve asset resilience by limiting weathering, heating/ cooling, wetting/drying and salt ingress.

Primary driver

To illustrate how ecological enhancement for biodiversity gains can provide additional engineering benefit, by improving asset resilience through limiting weathering-related deterioration. Tests were carried out in the field (Cornwall and Dorset) and in the laboratory.

Benefit

Benefits include improved asset resilience of hard structures with high cover of barnacles and seaweeds, that also provide supporting habitat for other species (AP-C7).

Cost

No direct data available.
Bioprotection may reduce required frequency of maintenance and repair/replacement by extending service life. Economic benefits will vary depending on type of asset, existing inspection and maintenance regime, and the type of materials, location and extent/type of biological growth. Compared to a non-enhanced option, financial benefits from reduced deterioration are estimated (based on expert judgement) to be low to medium over the medium- to long-term.

Engineering

Seaweeds: the range and extremes of surface temperatures were consistently reduced in field conditions under seaweed compared to bare surfaces, by an average of 56% and 25%, respectively. Short-term (minutes to hours) thermal cycling during low tide was reduced under seaweed (78%) as were variations in moisture (71%). Buffering by canopy-forming species of temperature and moisture reduced deterioration of mudstone rock. After 100 laboratory thermal cycles, loss of surface strength was reduced by more than 50% compared to bare rock, and actual breakdown of the material (measured as loss of mass) was reduced by up to 79%. Seaweeds are thought to reduce the frequency of damaging salt crystallisation events. Similar effects are expected for materials such as concrete.
Barnacles: compared to bare 'business as usual' surfaces, barnacle cover reduced peak temperatures (to 10 mm depth) by 1 to 5 degrees and short-term thermal cycling (15-30 minute) in the order of a few degrees, depending on material type (limestone, granite and concrete were tested). This is thought to limit damage to hard assets caused by 'fatigue' caused by repeated expansion and contraction.
The concentrations of damaging salt ions were also lower under a cover of barnacles compared to bare surfaces after a period of 2 to 3 years. The strength of these effects varied (positively) with barnacle abundance - the greater the cover of barnacles the greater the buffering effect.

Asset resilience

Results suggest that asset resilience to weathering related deterioration risks is increased through bioprotection.

Ecosystem Services

For details of possible ecological benefits, see specific enhancement measures in other case studies and AP examples. Reduced maintenance could improve ecological outcomes as disturbance to ecology would be reduced.

Social

Possible reduction in the frequency of repair/ replacement could reduce disturbance of local residents during repair works.

Policy

An 'additional' benefit to wider enhancement for ecological mitigation can help meet National Infrastructure Strategy goals of "improved multifuncionality, resilience and sustainability".

Further Information

Coombes, M.A., et al. (2017). Cool barnacles: Do common biogenic structures enhance or retard rates of deterioration of intertidal rocks and concrete? Science of the Total Environment 580, 1034-1045.

Coombes, M.A., et al. (2013). Bioprotection and disturbance: seaweed, microclimatic stability and conditions for mechanical weathering in the intertidal zone. Geomorphology 202, 4-14.

Gowell, M.R., et al. (2015). Rock-protecting seaweed? Experimental evidence of bioprotection in the intertidal zone. Earth Surface Processers and Landforms 40, 1364-1370.

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Art of the Possible

Eco-enhanced stormwater outfalls

COASTAL

AP-C10

What is the measure?

Prototype design of a wave tile (for a pre-cast concrete unit) to improve ecological and social value of stormwater outfalls; these outfalls are a common feature of coastlines worldwide and to date, are an infrastructure type where ecological enhancement potential has not been explored. The test tiles were deployed as retrofits for this trial but could be built into future pre-cast units using textured formwork.

Tests were carried out on wave exposed, open coasts in Cornwall, UK.

Primary driver

To test if we can improve the ecological suitability marine concrete infrastructure, compared with business-as-usual plain-cast concrete, whilst maintaining its use as a low tide footpath. It was specifically designed to create suitable crevice and water-holding habitat for mobile species along with a clear path for people to walk along – so that habitat and human activity can be catered for on the stormwater outfall.

Benefit

The overall social and ecological value of the wave tile compared to the business-as-usual standard option shows the high benefits of mult-ifunctional designs; with both public perception and ecological response of the test tile being greater than business-as-usual. The only additional cost for future applications would be design and production of textured formwork during the construction phase.

Cost

For this prototype, the cost of design, production and deployment of test tiles was approximately £2000 (~£1000/m^2). Re-using the silicone mould up to 20 times reduced the costs to £50/m^2. If using commercially available textured form liners, these may be a little more expensive to clean and re-use (~£8-30 per m^2 more than the business-as-usual).

Engineering

The test tiles did not compromise the engineering performance of the structure; future integral, pre-cast design and ecological colonisation of these would not affect performance, inspection or maintenance. In zones were barnacles were in high abundance, the biology may improve asset resilience to weathering-related deterioration (AP-C9) without impacting on human use of the outfall as a footpath.

Ecosystem services

A three-fold increase in animal and double the algal species diversity was found on the wave 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.

Social

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.

Further data

Metcalfe, D. 2015. Multispecies Design. Unpublished PhD Thesis. University of the Arts and Falmouth University.

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