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Facilitating ecological enhancement of coastal infrastructure: The role of policy, people and planning

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ABSTRACT

Urbanisation is recognised as a major pressure on coastal biodiversity. Increasing risks of flooding and erosion associated with future climate change indicate that new hard infrastructure will have to continue to be built – and existing structures upgraded – in areas of high social and economic value. Ecological enhancement involves undertaking management interventions at the design stage to improve the ecological potential of these structures, or to improve the ecological value of existing structures. Whilst scientific research into ecological enhancement methods and designs is growing, there has been limited discussion of the non-science drivers and mechanisms by which ecological enhancements can be successfully implemented in coastal infrastructure projects.

We explore the science–policy–practice interfaces of the ecological enhancement of hard coastal structures from three perspectives. First, we outline the growing number of European and UK policies and legislative instruments that are increasing the need to consider ecological enhancement in coastal developments. These serve as a facilitative tool for making enhancement projects happen, constituting a significant 'policy push' for research and application in this area. Second, we examine the role of people in influencing the uptake of ecological enhancements. The critical role of 'knowledge brokers' and the need for effective and sustained collaboration between a range of groups and individuals to get research approved operational trials off the ground is discussed. Third, we examine where in the typical planning, design and build process current enhancement projects have been embedded, serving to illustrate how the science can be used in practice.

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1. Introduction

Artificial coastal structures built for infrastructure (e.g., ports and harbours) and flood defence (e.g., sea walls and breakwaters) are ecological habitats in their own right (Glasby and Connell, 1999; Connell, 2001). In some cases, hard structures (e.g., those built from rock or concrete) may also facilitate climate-driven range extensions of species where there is otherwise a lack of suitable naturally occurring rocky habitat (e.g., Herbert et al., 2007). There is, however, growing awareness that the biological communities these structures support are typically impoverished compared to natural rocky shores (e.g., Chapman, 2003; Bulleri, 2006; Airoldi and Beck, 2007; Bulleri and Chapman, 2010). This is both a concern and a potential opportunity. With increasing flood and erosion risk associated with climate change and sea level rise the extent of coastlines that will need to be defended is likely to increase, and existing structures will need to be replaced or upgraded (e.g., Environment Agency, 2009; Defra, 2010). This is recognised as a major pressure on the conservation of intertidal habitats (Thompson et al., 2002; Moschella et al., 2005; Airoldi et al., 2005).

In response to these concerns, researchers have begun to examine how engineering design can be manipulated to achieve ecological goals, broadly termed 'ecological engineering' (e.g., Moschella et al., 2005; Chapman and Blockley, 2009; Coombes et al., 2009; Martins et al., 2010; Browne and Chapman, 2011). This can be used to achieve 'ecological enhancement', which aims to improve conditions for species through the modification of development activities undertaken primarily for non-ecological reasons (e.g., infrastructure or coastal defence) (Naylor et al., 2011a). Enhancements can therefore be used to increase the ecological value of structures relative to those that do not include enhancements. This necessarily involves setting clear ecological objectives that the enhancement seeks to achieve, whether a general increase in biodiversity (e.g., Chapman and Blockley, 2009), or supporting specific target species (e.g., Martins et al., 2010). Ecological enhancement can also provide social benefits, including educational and aesthetic opportunities (e.g., Burcharth et al., 2007), and in an engineering and heritage context, some of the organisms frequently found on hard structures (such as barnacles, fucoid algae and even microorganisms) may protect the surfaces they colonise against weathering and erosion (Naylor and Viles, 2002; Coombes et al., 2011; Coombes and Naylor, 2012); in these ways, biota may provide additional ecosystem services.

Whilst the growth of ecological enhancement research is encouraging, incorporating ecological criteria in operational coastal engineering is still in its infancy. This is perhaps unsurprising given that most hard structures are built for purposes other than ecological conservation, and whilst minimising environmental impacts is often a condition of planning, opportunities for actively improving ecological value are rarely considered (Chapman and Underwood, 2011). Indeed, any potentially favourable ecological outcomes are typically only identified as an after-thought (Bulleri and Chapman, 2010). For active enhancement to become more mainstream, there is not only a need to continue to observe interactions between artificial structures and ecology, but to develop and test ways to maximise ecological value operationally. There has, however, been little discussion of the non-science or 'practical' challenges to achieving this.

Environmental policy and practice is increasingly 'evidence-based' (e.g., Holmes and Harris, 2010) but the ecological enhancement research needed to provide this evidence is necessarily interdisciplinary, and requires considerable collaboration between different parties. This in itself presents a challenge because approaches to research design can vary between different disciplines, and different groups may often be interested in processes operating at different scales (Benda et al., 2002; Boulton et al., 2008; Tomlinson and Davis, 2010; Nobre, 2011). Furthermore, science researchers may have different aims, concerns and desired outcomes for enhancement projects than practitioners, including engineers and coastal managers (McNie, 2007). These kinds of challenges, and how they can be overcome, are not typically reported.

Here we seek to address this gap by highlighting how policy, people and planning instruments can be used to support the ecological enhancement of hard coastal infrastructure. First, we identify policy and legislative instruments (in Europe) that offer opportunities to support the inclusion of ecological enhancement in coastal developments. We place particular emphasis on policy levers able to facilitate dialogue between coastal scientists, engineers and managers. Second, we use examples from the UK to show the critical role of people (specifically 'knowledge brokers') in making applied research happen. Third, we use global examples to look more broadly at where and how opportunities to 'design in' ecological enhancements can fit in the typical planning (or consenting), design and build process for coastal structures.

2. The role of policy, people and planning in ecological enhancement

Operational ecological enhancement (i.e., undertaking enhancements in practice) is inherently multidisciplinary, involving a wide range of professionals and practitioners at different stages of the design and build process. Whilst flood defence engineers, construction managers and strategic planners may see enhancement as an 'extra' requirement, placing an additional burden on time and budget, teams concerned with conservation, environmental appraisal and policy may see enhancement as a means to ensure developments are compliant. Furthermore, undertaking ecological enhancement in practice provides valuable (and essential) opportunities for academic researchers to trial new designs, both in terms of their ecological outcomes and ease of implementation (i.e., engineering practicality and costs). These kinds of collaborations are challenging because science research and practice can operate at different timescales (e.g., Holmes and Clarke, 2008).

2.1. *Policy instruments*

Here we provide an overview of key European and UK policy instruments that either require or support consideration of ecological enhancement in the design and planning of hard

Table 1 – European and UK legal instruments that can be used to support ecological enhancement.

Legal framework	Salient points
European (UK transposition of)	
Convention on Biological Diversity (CBD)	Under CBD COP10, signatories are committed to objectives to integrate biodiversity values into all planning processes, to address the underlying causes of biodiversity loss and reducing (as close as possible to zero) the degradation of natural habitats. Ecological enhancement can assist meeting these requirements
EC Biodiversity Targets (to meet the International Biodiversity Convention)	The EU is committed to a significant reduction in the loss of biodiversity. Enhancements could be used to help meet this objective
EC Water Framework Directive	A key legal framework under which ecological enhancements will be delivered
EC Directive on EIA (85/337/EEC) and (97/11/EEC)	A key legal framework under which ecological enhancements will be delivered
SEA Directive (2001/42/EC), and 2004 UK Regulations	The Directive clearly provides opportunities for consideration of measures to enhance as well as mitigate against significant impacts on the environment
The Marine Strategy Framework Directive (Directive 2008/56/EC)	The Directive requires member states to achieve 'Good Environmental Status' in European seas by 2020. In addition to setting environmental targets and monitoring programmes, 'corrective measures' are required to ensure good status. Delivery of ecological enhancements can help achieve this
Habitats Directive 92/43/EEC & Birds Directive 79/409/EEC	Directive provides a hierarchy of avoidance, mitigation and compensation. Intertidal rocky habitats and species are not, however, included within the Annexes of the Directives, but ecological enhancement can nevertheless support maintenance of ecological connectivity (Article 10), and structures such as harbour walls and wind farms may offer opportunities for seabird conservation
UK	
Planning Policy Statement 9 (Biodiversity and Geological Conservation)	Provides a requirement to incorporate biodiversity enhancement into planning policies and planning decisions. Local authorities should assess the potential to sustain and enhance the biodiversity and geological resources of the area
Planning Policy Statement 12 (Local Spatial Planning)	PPS12 needs to take account of PPS9 requirements; however, it is not often that local authorities take a long term strategic view to the delivery of biodiversity enhancement
Marine and Coastal Access Act 2009 (England and Wales)	A system of biodiversity objectives and offsets could see the need for enhancement measures to be retrofitted or delivered through Marine Plans
Countryside and Rights of Way (CROW) Act 2000	Supports habitat protection and enhancement, and places a requirement on local authorities to have regard for biological conservation and enhancement in planning
Natural England and Rural Communities Act (NERC) 2006	Government guidance for implementing Biodiversity Duty advises that planning conditions and obligations are means for imposing mitigation and enhancement
Biodiversity: The UK Action Plan (UKBAP)	Improving the extent and abundance of priority habitats and species will clearly require biodiversity enhancement; however, few of these are specified in the rocky intertidal
Environment Act 1995	The duty to 'conserve' could include compensation in relation to developments adversely impacting National Park or waterbodies
Harbour Revision Orders (Harbours Act, 1964)	Ecological enhancements may be required as part of these permissions. Enhancements may be required to overcome holding objections made by statutory consultees during an application's consultation process for example

coastal structures. Table 1 summarises the policies and suggests how they can support ecological enhancement. We also identify important non-statutory drivers that may be used to aid the design and testing of different enhancement options.

2.1.1. *International context and European statutory requirements*

At the Convention on Biological Diversity (CBD) Conference of Parties (2010) it was recognised that nations had failed to meet previous biodiversity objectives, particularly that of ''halting the loss of biodiversity by 2010''. A new set of objectives was agreed by the parties. These include ''to integrate biodiversity values into all planning processes, to address the underlying causes of biodiversity loss and reducing (as close as possible to zero) the degradation of natural habitats'' (Table 1). All sectors including government, private sector and civil society need to work in an integrated manner to achieve these objectives and reverse current trends of degradation of natural capital. Mainstreaming the incorporation of ecological enhancements is required to deliver on these commitments under the CBD.

In Europe, the Water Framework Directive (WFD, 2000/60/EC) specifically sets condition targets for water bodies (including estuaries and coasts) as a statutory requirement. This legislation is particularly influential in the context of artificial coastal structures (both existing and future assets) as it outlines requirements for heavily modified water bodies (HMWBs) including all ports, harbours and defended coastlines (2000/60/EC Article 4/3). The target for HMWBs is for sufficient protection and enhancement measures to be in place so that they are considered to have 'good ecological potential', and that no deterioration of the associated water body takes place (Bolton et al., 2009). The need to improve understanding of structure–biota interactions as a tool for developing ways to achieve these targets should be seen as a significant driver of further urban marine ecology research in Europe. Aiming to achieve good 'potential' is perhaps more pragmatic and more realistic than striving to achieve the impossible of complete habitat creation (Ehrenfeld, 2000). This approach also allows iterative dialogue between stakeholders, regulators and scientists so that specific desired environmental states (e.g., Airoldi et al., 2005) are identified that are able to satisfy the requirements of all involved. These sorts of discussions are essential for setting realistic expectations with stakeholders (Box, 1996).

Compared to the WFD, the Habitats Directive (1992/43/EC) and Birds Directive (1979/409/EC) have less potential to act as levers for ecological enhancements as the specific habitats and species listed in the Annexes do not include rocky intertidal areas. However, Article 10 of the Habitats Directive emphasises the importance of ecological connectivity amongst habitat patches and species' populations; ecological enhancements that maintain and enhance ecological connectivity across the wider environment could therefore support the Habitats Directive and the Birds Directive (Table 1).

The Strategic Environmental Assessment (SEA) Directive (2001/42/EC) and Environmental Impact Assessment (EIA) Directive (85/337/EEC and 97/11/EEC, respectively) outline a tiered process of impact assessment for new developments. SEAs and EIAs are undertaken as a preventative strategy, aimed to assess all environmental consequences of developments before any construction commences (Wood, 2003). As part of the SEA process, developers are required to outline measures to prevent or reduce adverse environmental effects (Article 5-3). Such 'mitigation measures' could include limiting or reducing the degree, extent, magnitude or duration of any adverse impacts (Sheate et al., 2005; Defra, 2009). In addition, marine-specific directives have recently been adopted (e.g., the Marine Strategy Framework Directive, 2008/56/EC) requiring member states to achieve 'Good Environmental Status' in European seas by 2020. In addition to setting measurable environmental targets and monitoring programmes, member states will be required to develop "corrective measures...to revert poor status into good status" (Borja, 2006, p. 240). Whilst defining exactly what constitutes 'good' status in environmental policy remains largely ambiguous, the sorts of ecological enhancements being developed and tested for hard coastal structures should offer opportunities to assist with meeting these broad targets. There is also considerable potential for enhancements to be considered as part of environmental assessments required by international organisations such as development banks. Consideration of this is beyond the scope of this paper but merits attention.

2.1.2. UK statutory requirements

There are several tools and regulations within the UK planning system that stipulate ecological consideration in new developments, including at the coast (Defra, 2009). These requirements must be met if the necessary planning permissions and licences are to be obtained. For example, Sustainability Appraisals (SAs) are assessments of impact similar to SEAs, but which have a stronger focus on social and economic appraisal (Burcharth et al., 2007). The Department of Communities and Local Government (DCLG) provides guidance on statutory planning provisions for Local Authorities through Planning Policy Statements (PPSs). Ecological considerations are specifically addressed in PPS9 (Biodiversity and Geological Conservation), which states that new developments should be refused permissions where significant environmental harm cannot be prevented, adequately mitigated against or compensated for. Biodiversity enhancements are also required under PPS9 wherever possible. PPS25 (Development and Coastal Change) also provides additional impetus for ecological considerations in coastal zone development.

The UK has also recently ratified Marine Bills for England and Wales and Scotland; Northern Ireland has yet to be ratified. One of the primary purposes of the Marine and Coastal Access Act in England and Wales is to enhance the marine natural environment for current and future generations. The bill stipulates that 'marine environmental matters' incorporate "the conservation or enhancement of natural beauty...the conservation of flora and fauna dependent on, or associated with, a marine or coastal environment" (House of Commons, 2009, p. 102). For ports and harbours, key legislation requiring consent are Harbour Revision Orders (Table 1). These are managed by the Marine Monitoring Organisation (MMO), with applicants applying for permission to construct new harbours and/or to improve, maintain or manage existing facilities (Naylor et al., 2011b).

2.1.3. Non-legislative drivers

Non-mandatory drivers for ecological enhancement include raising public awareness and acceptance of a new development (if enhancement is included), improving success with planning applications (which may be seen as a particular advantage for developers) and increasing chances of securing funding to support the activities. A good example of this is the Seattle Seawalls project (https://sites.google.com/a/uw.edu/seattle-seawall-project/home (accessed 3.08.11)). For this project the University of Washington was commissioned to conduct a pilot study of ecological enhancement options for a seawall as a precursor to a planning application by the City of Seattle for replacement walls. The primary ecological focus of trial was to test designs most suitable for supporting declining Pacific salmon stocks (Goff, 2010). In addition, the City of Seattle funded the pilot study to help win the support of the public (and other interest groups) and to increase the chance of securing much-needed Federal funding to reduce locally incurred costs (Noble, personal communication, 2011). Such preliminary enhancement trials can be used to advance scientific understanding as well as aid the planning process, support wider conservation targets and increase public acceptance of new developments.

2.2. *The role of people as knowledge brokers*

There is growing awareness by government bodies and academic researchers of the value of effective science–policy and science–practice interfaces (e.g., Holmes and Clarke, 2008). Social science research focussing on science–policy interfaces argues that where a plurality of disciplines and views exists there is a need for selected individuals to act as 'knowledge brokers' or interpreters (e.g., Cash et al., 2003; Holmes and Clarke, 2008). Knowledge brokers are intermediaries who serve to bridge between the producers and users of knowledge. They can facilitate interactions between these groups or translate the information to make it relevant for the end-user. Critically, knowledge brokers have a knack of helping people see the value of (in this instance) 'an enhancement' from their perspective, taking the time to understand different perspectives and having a solid understanding of the political, economic and other factors influencing a decision. For example, for engineers, construction managers and strategic planners, effort must be made to sell the notion of ecological enhancement as a means of helping to meet some of their legislative requirements and key performance targets.

Notably, much of the existing research on knowledge brokers has focussed on the theory and frameworks within which they can operate (e.g., Ward and Hamer, 2009; Meyer, 2010). Whilst it is fundamentally important to understand this, there have been fewer attempts to demonstrate how knowledge brokers operate in practice (see Runhaar and van Nieuwaal, 2010 and Sheate and Partidario, 2010, for exceptions). We use two examples (Sections 2.2.1 and 2.2.2) to illustrate the critical role of knowledge brokers in making coastal ecological enhancement research happen.

2.2.1. *Knowledge brokers in collaborative applied research*

This first example outlines and discusses the key human dimensions of a government agency co-funded doctoral research project, which led to the delivery of academic research of value to a wide range of end-users and importantly, which was re-packaged into a readily accessible format that policy and practice staff can readily use (see www.exeter.ac.uk/coastaldefencesbiodiversity (accessed 25.09.11)).

For this project, a knowledge broker was pivotal in identifying an appropriate funding stream and developing a firm business case for the research. Fig. 1 illustrates the range of groups the knowledge broker was required to engage with in the research institutes (two Universities) and the business partner (the Environment Agency) to build interest, support and a suitable team to undertake the research. A key role of the knowledge broker was to promote the research idea within both the research and operational arms of the organisation to help win support for competitive internal funding. Knowledge brokers therefore need to be aware of key business, policy and operational needs and ensure that the research idea meets the requirements of the different parties involved.

Once this sort of project is approved, the role of the knowledge broker is equally important. In this case, the

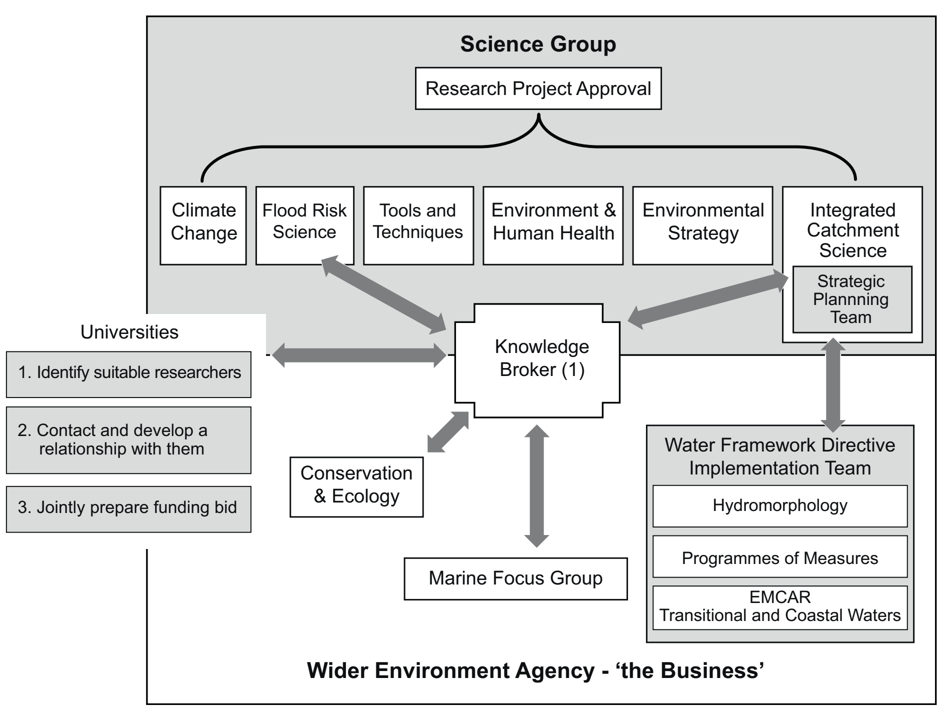

Fig. 1 – Flow diagram illustrating the interactions within a government agency and research institutions needed to secure research funding. The Science Group (currently called Evidence) is one part of the Environment Agency and in the context of this example, a scientist in the group was the knowledge broker interacting with the wider business. EMCAR stands for Environmental Monitoring Classification Assessment and Reporting.

end-user project manager's role involved maintaining existing – and establishing new – networks of interested individuals in the government agency to make best use of the science funding. They also served as the industrial supervisor on the PhD research project, using their organisational insight to inform the scientific research design. This, along with assembling a broad-range of experts to work on the project team, helped ensure that the science tested was salient and credible to the end-users who would ultimately apply the research (McNie, 2007).

The project was comparatively well-funded, with considerable flexibility in terms of research expenditure. This flexibility was pivotal in ensuring that the researchers could spend time developing a wide range of engagement tools and relationships with a wide-array of end-user organisations, and using this knowledge to inform and enhance the research process (Nobre, 2011). For example, the internal networks within the end-user organisation presented the project team with the unique opportunity of helping design the first operational enhancement trial in the UK (see Section 2.2.2). Without flexibility in the project's budget and schedule, it would not be possible for these kinds of activities to happen, particularly given the tight operational timeframes often required by engineers in development works.

An outcome of this collaborative project has been the production of guidance documents, which serve as practical 'process manuals' for practitioners on the science, policy and practice of including ecological enhancements in hard coastal infrastructure (i.e., what McNie, 2007, terms the 'promotion phase'). The first (Naylor et al., 2011a) was commissioned by the original project co-funder (the Environment Agency) as a means of translating the doctoral research (Coombes, 2011) into a format that could be readily used by operational and policy staff (see www.exeter.ac.uk/coastaldefencesbiodiversity/EA-guidance.html (accessed 25.09.11)). The main goals of the guidance were to raise awareness about the potential for ecological enhancement, including policy levers that can help facilitate the process, to demonstrate the potential simplicity (relative to preconceptions) and low cost of enhancements, and to provide some examples of scientifically robust enhancement designs tested to date.

This 'translation' process required the authors to broker between the different writing styles and terminology used by academics, practitioners and regulators (Benda et al., 2002). It also required continued dialogue and clarification, where the knowledge from practitioners and regulators greatly enhanced the practical value of the guidance – because the science was better situated within the operational context of

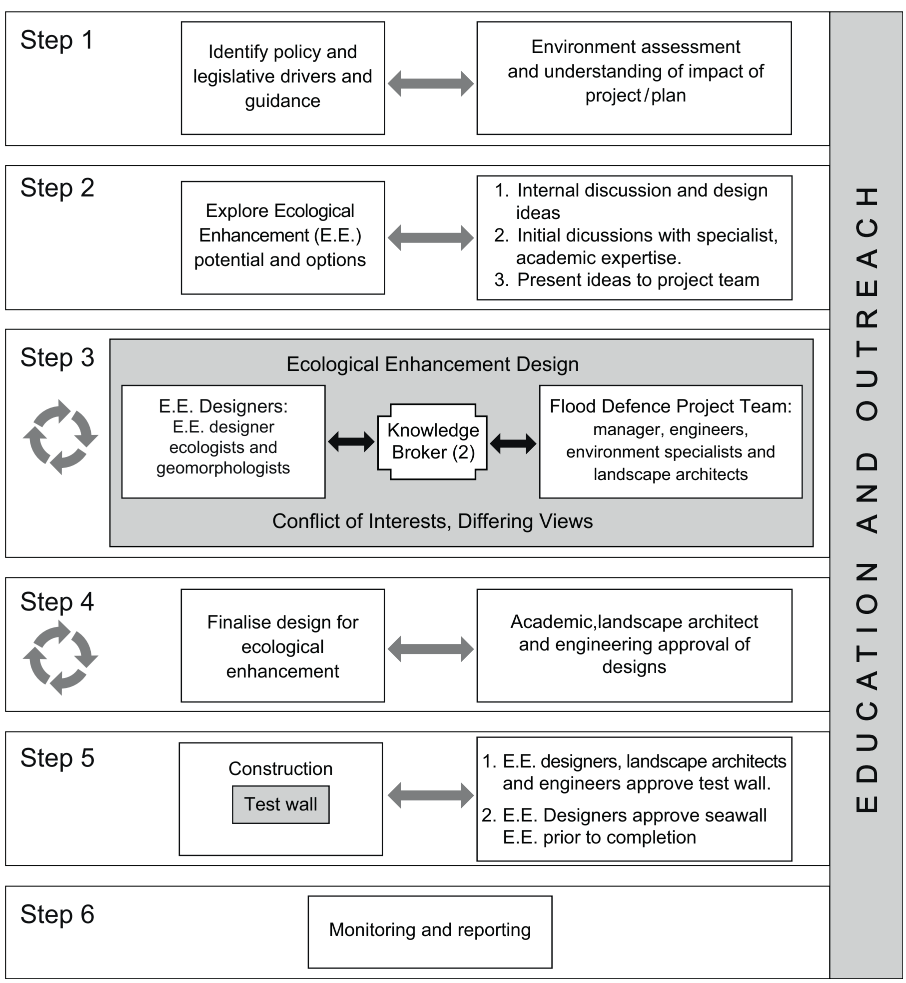

Fig. 2 – Flow diagram illustrating the key phases, tasks and processes required to achieve an operational ecological enhancement trial as part of the Shaldon and Ringmore Tidal Flood Defence Scheme, Devon, UK.

the organisation commissioning the work. Such efforts are needed to instil a common knowledge structure (i.e., Boulton et al., 2008) to ensure that the terminology used is comprehensible to all those involved, and is consistent and suitable for both academic and management audiences (Memmott et al., 2010).

This example demonstrates the pivotal role played by knowledge brokers in government regulatory bodies; their networks and understanding of policy, and operational, regulatory and academic science is essential to funding and delivering projects that meet policy and practice needs. The willingness of all members of the working team to conduct research with continued communication and clarification was essential for the production of 'brokered knowledge' (Meyer, 2010), leading to the delivery of high quality academic and, ultimately, useful applied science.

2.2.2. *Knowledge brokers in operational trials*

This second example and associated diagram (Fig. 2) illustrate the process involved in establishing the first known ecological enhancement of new-build coastal defence infrastructure in the UK (the Environment Agency Shaldon and Ringmore Tidal Defence Scheme in Devon). The enhancements adopted for this scheme involved a series of modifications to the mortar between stone blocks on two vertical estuary walls. This included creating grooves, holes and pools to create shaded, water-retaining microhabitats (see Naylor et al., 2011a for more details).

Step 1 (Fig. 2) of the process involved understanding the policy drivers supporting enhancement and any legislative requirements for enhancement (the EIA in this case). Enhancement tends to be either proposed by knowledgeable persons in the permitting authority or derived from the environmental assessment work accompanying planning applications. This step is needed to determine whether ecological enhancement for a proposed development is identified as a statutory or mandatory requirement, or a voluntary arrangement of benefit to a project (Section 2.1).

Step 2 (Fig. 2) involved a rapid appraisal of feasibility as part of the works, and gaining initial buy-in to the concept of ecological enhancement by key members of the project team. These activities need to involve a cyclical and iterative process as the structure design develops, and as the impacts associated with the project become more explicit. Given that there are likely to be multiple demands on project monies, there may be a temptation to see cuts in conservation as an easy win. This is unfortunate given that enhancement measures are likely to constitute only a fraction of the total scheme design and construction costs. In this case, the Scheme cost £6.5 million pounds in total, with the enhancement element constituting approximately 0.3% (including in-kind contributions). These costs were low for consultancy due to the fact that there was considerable input by the contractors; the academic input was initiated via an existing research project which reduced experimental design and preliminary trial costs; the actual enhancement was built into a small area of the overall scheme. As well, there was no pre-trial monitoring and post-trial monitoring was limited to one year. Understanding and communication of the policy drivers, environmental outcomes and the public relations benefits associated with ecological enhancement measures is also vital at this point. The ownership of the delivery of enhancements by a knowledge broker and the core team members is crucial to ensure this happens, and requires enthusiasm and commitment of time on both the science and practice sides of the project.

Step 3 (Fig. 2) involved an initial site visit by the enhancement designers and project team members to discuss design options, their feasibility and the potential outcomes. In this context it is important to recognise that some developments will offer greater potential for ecological benefits than others. This will be a consequence of the environmental setting (location in the tidal frame, wave exposure, gradient etc.) and the type of structure. It is worth noting that in relation to this specific scheme the setting of the walls in the intertidal was quite high relative to sea level (around MHWN), so the potential for biological uptake was perhaps less than that for a structure lower in the tidal frame. Thus, the type of flood defence (a vertical wall), its position, the materials planned for construction and the proposed construction methods were all considered to reach a decision on, firstly, whether or not to introduce enhancement and, if so, how best to do so (Steps 3 and 4, Fig. 2). Incorporation of enhancements is only likely to be achieved through regular consultation, via the knowledge broker, between the enhancement design team (academic researchers in this case) and the scheme designers and asset owners (the Environment Agency). The need for committed individuals and considerable time and energy is a common theme in successful environmental science delivery (Holmes and Clarke, 2008).

A key activity was the construction of a 'test wall' to trial the planned enhancements. This gave the opportunity to test the 'buildability' of the design with the contracted engineers, overcome some of the aesthetic concerns associated with the project and, ultimately, ensured all involved were happy with the plans prior to the start of construction. These kinds of activities are essential to maintain enthusiasm and to resolve any potential conflicts as early as possible. After construction of the test wall, designs were approved by the project team and construction of the final walls was completed in June 2010 (Step 5, Fig. 2).

The final step in the process (Step 6, Fig. 2) is monitoring and reporting. Robust and appropriate monitoring of the ecological outcomes of enhancements is critical to contribute to scientific knowledge and more broadly to provide evidence of – and evaluate the success of – the particular designs used for each party involved. Monitoring of the enhancements is currently on-going.

3. Embedding ecological enhancement in the planning process

The research and collaborative interactions detailed in examples Sections 2.2.1 and 2.2.2 were used to inform the production of two end-user focussed guidance documents (Naylor et al., 2011a,b). Through our discussions with a variety of end-users (including concrete companies, ports, harbours, consultancies and government regulators) it became clear that one of the most effective means of ensuring successful uptake

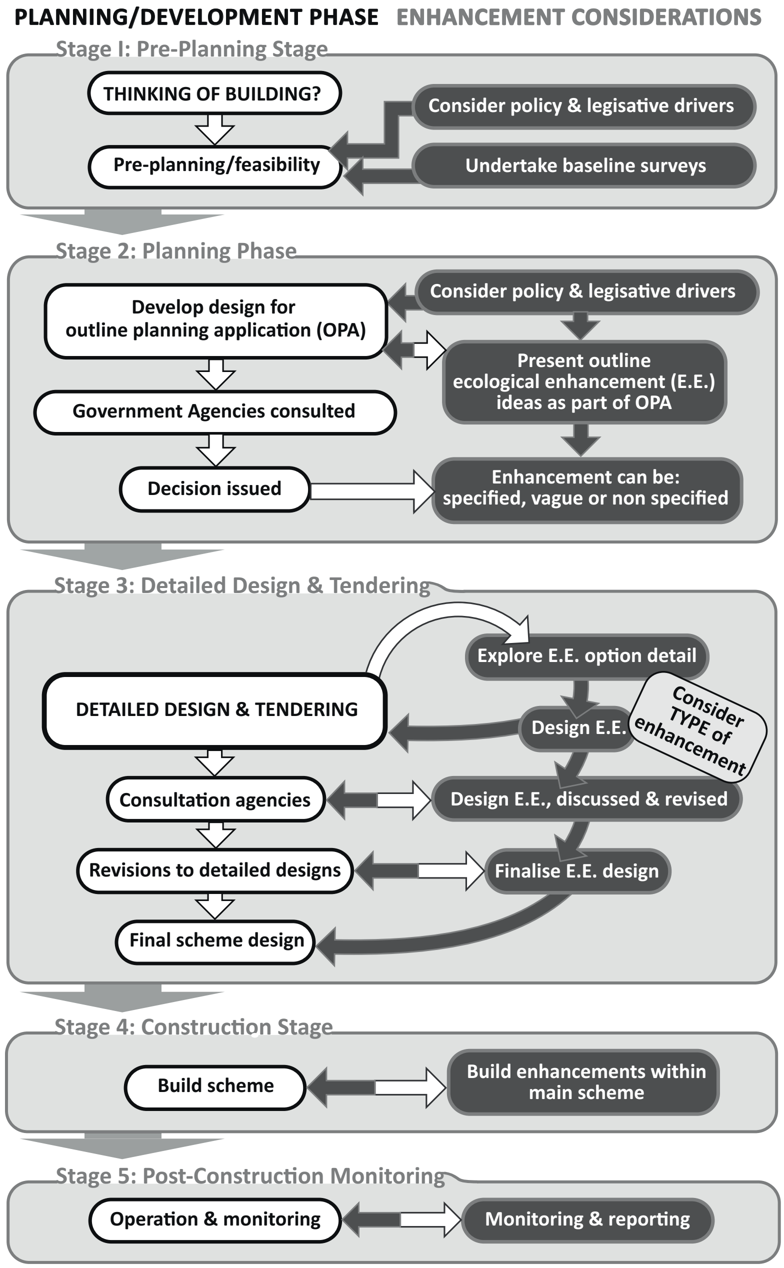

Fig. 3 – Flow diagram showing where in the planning and development process ecological enhancements of hard coastal structures can be considered and embedded, after Naylor et al., 2011a. A combined design and build tender is often issued for many schemes; in this situation, Stages 3 and 4 are combined.

of the guidance was to link the science and policies supporting ecological enhancements to an operational framework. Thus, the planning (or consents) and development framework was used to demonstrate where and how in the planning process ecological enhancements could best be considered and implemented.

Organisations proposing substantive repairs or new hard coastal infrastructure must adhere to planning guidelines and other applicable legislation (see Section 2 above). Several stages in the planning and consenting processes were identified for new (or substantive repairs to existing) coastal infrastructure, where ecological enhancements could be considered (Fig. 3 after Naylor et al., 2011a). Case study examples from scientific research and operational trials to date were also used to illustrate opportunities for enhancement at each stage of the planning process. For example, at the pre-planning/planning stage of a project (Stages 1–2 in Fig. 3) construction materials may be selected. It is here where scientific evidence of the influence of material type and texture on ecological outcomes (e.g., Coombes et al., 2009; Martins et al., 2010) can be used to inform decisions. Stages 1–2 (pre-planning and planning) are where 'non-mandatory' drivers for ecological enhancements have occurred (see Seattle example in Section 2.1.3 above). In the guidance, we also set out a series of key questions for practitioners to consider at each planning stage to help them evaluate how and where enhancements could be included in the proposed development. Feedback from launching the guidance suggests that the process of linking opportunities for enhancements to planning and/or consenting structures can make this kind of guidance far more useful for practitioners (Skinner, personal communication, 2011; Wilson, personal communication, 2011). In future, inclusion of ecological enhancements in operational projects could be facilitated by more firmly linking the connections laid out in the guidance to regulatory requirements. For example, institutionalising the knowledge brokering process between regulatory bodies (or asset owners) and scientific institutions may lead to increased uptake of ecological enhancements.

4. Conclusions and recommendations

There clearly remain many questions that need to be addressed through future ecological enhancement research and practical applications such as those outlined here. Given the gap between legislative and policy drivers encouraging or requiring enhancement and the amount of available research in this subject area, there is an urgent need for more research. This research needs to be interdisciplinary and in collaboration with key end users. Well-designed and well-executed collaborative academic-practitioner research projects can be used to improve our understanding and design of ecologically robust operational trials, such as those implemented in Seattle (Simenstad, 2009), Sydney (Chapman and Blockley, 2009) and Shaldon (this paper). These kinds of collaborations are especially important in this field as researchers are unlikely to have the resources to build full-scale structures with enhancements to study themselves. Effective global coordination and record-keeping between teams designing, testing and implementing ecological enhancements will also ensure a robust evidence base is more swiftly achieved.

Ecological enhancements designed for engineering works should seek to address two issues. Firstly, to meet the legislative, policy or non-legislative targets relevant to the particular scheme and location in question and, secondly, to design enhancements so that they are scientifically robust enough (with suitable replication for example) to be used as case studies for future designs. This level of rigour and goal setting is often lacking in operational river restoration schemes (e.g., Bernhardt et al., 2005), but is essential to ensure that a sufficient evidence base is developed (Holmes and Harris, 2010). It is also essential to establish exactly what the expectations and requirements are of different stakeholders (Box, 1996; Ehrenfeld, 2000). If there are conflicting views it is critical that appropriate engagement occurs to help ensure that the design is best suited for all requirements (including legislative, ecological and social) (Tomlinson and Davis, 2010; Nobre, 2011). Documenting how this is successfully navigated is as important as the scientific design criteria and policy levers underpinning them, as this information will help better manage the human dimension of future ecological enhancement schemes.

The collaborative research outlined in Section 2.2 highlights the critical role of knowledge brokers in enabling high quality scientific research of relevance to policy makers and practitioners. Other key attributes that contributed to the success of these applied science projects include: (a) allowing sufficient time for iterative discussions to agree research/operational design requirements to help win the support of a diverse group of vested interests; (b) having sufficient flexibility and budget to allow for wide-ranging engagement, to be able to incorporate unexpected opportunities into the research process and to meet operational timescales; (c) working closely with end-user collaborators throughout the project, and using the insight and knowledge they gain through internal networking to inform the research design, and; (d) drawing on the expertise of the suite of end-users involved in the subject area (including the people commissioning, planning, designing and building) to understand when and how ecological enhancement can be effectively embedded into their working practices.

Using ecological enhancement of hard coastal infrastructure as a case study, this paper provides examples of how knowledge brokers operate in practice – to help navigate science, policy and planning domains. Involvement of knowledge brokers led to successful identification of opportunities for enhancement and the re-packaging of research outputs in an accessible form for end-users. It also enabled ecological enhancements to be designed and tested as part of new coastal infrastructure projects. These successes were made possible by a committed, enthusiastic suite of people who served as effective knowledge brokers.

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