Developing an Estuarine Planning Support System: An integrated tool to managing contaminated sediments in coastal and estuarine environments

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Introduction

Estuaries are globally important areas for many uses and users including industry, tourism, and biodiversity. Due to their unique position at the interface of marine and freshwater ecosystems they are vulnerable to a variety of physical and chemical anthropogenic stresses [1]. The increase in the range and intensity of human activities in coastal areas has increased pressure on estuarine and associated coastal resources, often with adverse effects on the environment and society [2,3,4,5,6]. To prevent unacceptable pressures and facilitate a sustainable development, a rapidly growing number of policies, politics, administration and legislation have been developed around the globe since the 1970s [7]. While these regulations have been powerful tools to decrease destructive anthropogenic impacts on estuaries, the sheer amount of different regulations on local, regional, national and international levels can lead to misinterpretation and omitting of relevant protection methods.

In Europe, recent marine and estuarine management has therefore developed a set of concepts and tools in order to simplify the process of impact assessment and to communicate their results with scientists, regulators, policy and decision makers as well as the public [1,8,9,10,11,12]. These concepts and tools for managing estuarine, coastal and marine areas include: sectoral management schemes [13,14,15,16]; ecosystem services and societal benefits [1,10, 17,18]; environmental integrative indicators [19,20), and the 10-tenets for successful and sustainable management [21,22].

However, despite being central to the integrated implementation of several EU directives and national governance mechanisms, the currently available tools are not interlinked; leading to potential omissions and waste of recourses [15,23, 24, 25, 26,27, 28].

For the presented study, the conceptual framework described in [2] was used as the basis for a Geographic Information System (GIS)-based tool. The overall aim was to bring together relevant marine management tools, concepts, data and assessment protocols to produce an effective Estuarine Planning Support System (EPSS) tool. The specific objectives were:

1. To use maps and matrices for estuarine relevant features (e.g. habitats, uses, users, ecosystem services, etc.) to summarise the knowledge and understanding the baseline(s) environmental condition of the estuary;
2. To investigate the different management schemes and frameworks and integrate these into a novel framework;
3. To build on the EPSS framework developed by [2] so that the tool will identify current ecosystem services and determine the societal goods and benefits taken from the system;
4 To develop software that provides a practical application of the EPSS framework including the identification and advice on potential impacts of developments in the Humber Estuary.

The EPSS aims to provide an integrated approach to simplify the process of assessing and managing an ecosystem (in its current state and possible future states) and in determining whether an application for a development should be granted or a policy should be implemented. It is an informative tool for the applicant and/or regulator regarding the relevant legislation, requirements and receptors rather than providing an actual assessment or decision regarding an application or policy.

Method and Data requirements

The EPSS software comprises of an interactive GIS tool that analyses local socio-economic, environmental and regulatory information to provide guidance and advice regarding the potential environmental and social impacts of such a development or operation. The tool was developed in ArcGIS for Desktop 10.1 and scripts were written in Python 2.7. The script has been written to utilise data "look up tables" so that no data had to be hard-coded in the script, allowing the tool to be updated with new advances.

Data

Socio-economic, environmental and regulatory data from regulatory, government, privately-owned and scientific publication sources can be used as input data to inform the tool. The data requirements for the tool are conservation designations (e.g. Special Areas of Conservation, Special Protection Areas, Sites of Special Scientific Interest, Marine Conservation Sites, and sites protected under the RAMSAR Convention in the UK), marine sediment testing data, Water Framework Directive (WFD) status (in Europe), objectives and reasons for waterbodies not reaching Good Ecological Status/Good Economical Potential (under the WFD), environmental legislations, disposal sites and sites protected for their archaeological or cultural importance. The more detailed information is available, the more robust is the provided assessment, but the tool can be used without a comprehensive dataset which is highlighted in the output.

Identification of Receptors

In the EPSS tool, receptors are defined as ecological (e.g. conservation areas, marine/ protected areas, birds, mammals) or economic (e.g. beaches, infrastructure, shipping, fishing) entities which are sensitive and therefore could be affected if exposed to a hazard.

To determine the range of potential impacts related to e.g. a new policy/infrastructure project and identify what receptors may be impacted upon, boundary conditions were applied to represent the minimum and maximum expected influence. These boundary conditions were based on the most conservative conditions reported in previous studies e.g. [30, 31].

Identification of stakeholder interests and potential conflicts

Using a full input dataset, the tool provides comprehensive information and guidance regarding applicable local legislative frameworks and requirements while still leaving the actual assessment/final decision regarding the implications with the user. It provides guidance and allows the user to save time but does not remove the responsibility. This makes the tool useful for regulators, industry, science and socio-economists alike, who need an understanding of the range of relevant legislative frameworks, potential stressors, ecosystem services and societal goods and benefits provided by an area.

Any development project/operation or policy within an estuary has the potential to create spatial and/or temporal conflict between the different uses and users of its societal goods and benefits, due to the limited area and resources available [31, 32, 33, 34]. To determine the conflicts, and hence provide the information needed to manage them, the tool identifies ecosystem services and societal goods and benefits through a conflict matrix against the different land uses. With the conflict matrix, the user can identify where conflicts and unsustainable activities might occur. Conversely, it can be used to identify beneficial or no impacts between activities.

The tool identifies the specific stakeholders by relating the proposed development/policy/ operation type to the identified local receptors. This enables the user to determine the current conflicts which may be occurring within the estuary to inform future stakeholder communications as well as impact assessment. Individual legislative frameworks currently integrated in in the tool are the Planning Act (2008), Environmental Impact Assessment Directive (2014/52/EU), Marine and Coastal Access Act (2009) and the Water Framework Directive.

Case Study – Dredged Materials in the Humber Estuary

Dredged materials are sediments removed from the bottoms of navigable waters (e.g. rivers and harbours) to maintain navigation channels (http://oceanservice.noaa.gov/facts/dredging.html). As navigable waters in need of dredging are usually industrially used waterways, sediments removed from these areas can pose a significant risk to the environment they are dumped in, due to the potential high contents of hazardous pollutants [35,36]. The dumping of contaminated dredged materials can introduce and mobilize these hazardous contaminants in the receiving aquatic environment making them available for the local flora and fauna [35,37,38]. Of particular concern is the potential release of lipophilic, persistent organic pollutants (POPs) such as dioxins and furans (PCDD/Fs) polychlorinated biphenyls (PCBs) [36], polybrominated diphenylethers (PBDEs) and polychlorinated naphthalenes (PCNs), organochlorine pesticides [37] and polyaromatic hydrocarbons (PAHs) [36,38] that are known to accumulate in sediments (especially from industrial areas) and can be stored in these sediments for decades [37,38].

The tool was used to evaluate the environmental risk and relevant legislations of a fictive dredging operation in the Humber Estuary. The Humber Estuary (below mean high water) was chosen due to its importance for economic and biodiversity factors alongside a complex legislative background within which users must work (Lonsdale et al., 2015). The Humber Estuary begins at the confluence of the River Ouse and the River Trent and

then flows easterly where it enters the North Sea between Spurn Point and Donna Nook (bounded by coordinates: 53.807, -0.92; 53.335, -0.92; 53.334, 0.184; 53.81, 0.188 (WGS184)).

Discussion

Limitations of the EPSS tool

The extent of the impacts was determined in the absence of accurate data regarding the estuary's physical-related properties, such as its hydrodynamics, but it has been developed using the highest quality publicly-available evidence compatible with ArcGIS 10.1. The tool has been developed to help decision makers, developers and stakeholders consider the environment, the legislative requirements and the receptors and impacts. While it provides advice regarding what should be considered in any assessment or application, it does not provide the assessment on the applicant's behalf given the ongoing requirement for expert judgment and interpretation. Furthermore, it does not yet include information regarding environmental legislation outside of Europe. However, the tool is sufficiently flexible so that these aspects can be added in the future. The data behind the assessment of dredged material is based on those samples analyzed for the applications made under the Marine and Coastal Access Act. In the future, the results from other monitoring programmes such as the English disposal site monitoring programme could also be used to increase the evidence base

Conclusions

An EPSS tool has been developed covering a set of objectives to provide guidance and advise the user (regulators, decision makers, NGOs, researchers and public) of the legislative requirements of a project in the marine environment together with guidance on conflicts, ecosystem services and societal goods and benefits. The EPSS tool can save time and resources, aid in the decision-making process and make the decision process more transparent and consistent. The tool has been developed to be flexible in its approach to allow it to be used internationally and to allow for it to be adaptable for future changes. It combines the many aspects required for a holistic approach to marine management from the inclusion of governance and stakeholder views to the need for and use of monitoring information (Elliott et al., *in press*).

Using the tool to assess the environmental risk and relevant legislations and receptors for a dredging project in the Humber Estuary have shown the benefits and flexibility of the tool in a complex system. It demonstrates that an integrated tool can be applied to a complex environment for developers and decision makers to navigate through the complex legislative drivers highlighting the risks associated with dredge and disposal projects taking into account the project specifications and contamination levels on the environmental and socio-economic receptors within the vicinity.

Acknowledgements

We would like to acknowledge and thank Cefas for their financial support of the doctoral study of the first author, within which this research was undertaken.

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