Ecosystem Services – An Approach for Sediment Management

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Abstract. The ecosystem services approach involves classifying, describing and assessing the monetary value of natural resources in terms of the benefits that humans can derive from nature. An ecosystem services assessment has been developed and applied to the sediment management aspect of a harbour development for a scale typical for Ireland. Two sediment management techniques have been analysed for the sediment generated from dredging for the project; wetland creation and the widely practised disposal at sea. The wetland creation approach is consistent with the eco-friendly concept of ‘Building with Nature’ and also the circular economy. The ecosystem services assessment applied to the disposal at sea option yielded a negative overall monetary value (-€191,878/year) and the wetland creation option resulted in a positive overall monetary value (€1,403,275/year). These assessment results indicate that a ‘Building with Nature’ solution beneficially using dredged sediment can provide significant monetary benefit in the form of ecosystem services, for a sediment management project of this scale. This ecosystem services approach can contribute significantly to assessment of a sediment management projects and can inform stakeholders and policy makers of the benefits of ‘Building with Nature’ solutions.

Keywords: Dredging, ecosystem services, sustainable, sediment management, resource, circular economy.

1. Introduction
Dredging is the removal of sediment from the bottom of harbours, lakes and other water bodies, such as navigational channels, berthing areas, and marinas. It is essential for the maintenance and development of ports and is a key feature of national and international infrastructure and of vital economic importance to worldwide trade and commerce. It is estimated that between 200 and 250 million tonnes of marine sediment are dredged annually in the EU [2] with the Netherlands, Belgium, France and Germany accounting for approximately 70% of this [35]. The quantities of dredge sediment generated internationally is also significant with the United States dredging 230 million tonnes annually [43]. In Ireland approximately 1.8 million tonnes is dredged annually [23][36], which is significantly lower than for other countries, but the importance of dredging Ireland’s navigational channels is critical as Ireland’s main ports and harbours account for 99% of Ireland’s imports and exports by volume and 95% by value [38].

In Ireland, dredged sediment is classified as a waste under the Waste Management Act and requires a license or a permit (depending on the quantity), if the sediment is treated or stored on land [10].
Waste Framework Directive, indicates that dredged sediment can be used as a resource and not as a waste, if certain criteria can be met [17].

Sediment management is a key aspect of a dredging project and in general dredge sediment may be managed by disposal, treatment and/or beneficial use. The disposal approach may be: unconfined disposal at sea, confined disposal at sea or land disposal. There are many techniques used for the treatment of sediment and depend on the sediment characteristics and the intended use of the sediment. Beneficial use options are many and one general approach to categorization is as follows [22]:

Engineering uses (substitute for land based resources e.g. sand, aggregate, rock), Environmental Enhancement (wetland creation, sediment cell maintenance and fill for abandoned mines) and Product Uses (sediment used to form useful products e.g. manufactured topsoil, road sub-base construction and landfill liner).

Numerous studies provide greater detail on the various sediment management beneficial use options including United States Army Corp of Engineer (1987, 2007, 2015), PIANC (1992, 2009a, 2009b) and the OSPAR Commission (2009). Recent research in a European context includes the PRISMA Project (2014), the CEAMaS Project (2015), the USAR Project (2016) and the SURICATES Project (2018), all funded by the EU Interreg Programme.

Although Ireland generates a low sediment volume relative to many other countries, it encounters many of the same challenges experienced by larger countries. The main sediment management challenge is seeking an alternative to disposal at sea for primarily clean uncontaminated sediment, in particular the finer grained fraction of the sediment. The management method(s) suitable for dredge sediment depend on a number of factors including physical characteristics, contamination levels, volume of sediment, how and where the sediment is dredged, available beneficial use opportunities, engineering acceptability and local practice. These factors are considered when undertaking a feasibility study of the sediment management options including completion of technical, economic, environmental and ecosystem services analyses in addition to legislative and societal aspects. This paper primarily focuses on the ecosystem services aspect of dredge sediment management.

2. Ecosystem Services Approach to Sediment Management

2.1. Background to Ecosystem Services

Ecosystems are dynamic environments and can include a wide variety of species. This biodiversity is critical to the health of an ecosystem. Ecosystems can come under pressure in two forms, natural and human [19]. From a dredging perspective, human pressures on ecosystems include the construction of marine infrastructure projects (e.g. port developments) and the act of dredging itself can be destructive to habitats, if not managed correctly. It may be noted that the negative changes that ecosystems have experienced due to human pressures have resulted in significant gains to human well-being and economic development [26].

Westman (1977) first investigated the complex link between ecosystems and economic systems [47]. Ehrlich & Ehrlich (1981) coined the term ‘ecosystem services’ and in the following decade, ecologists and scientists further examined the concept that ecosystems are life-support systems, providers of ecosystem services and economic benefits [8][12][18][28]. In the late 1990’s the concept of valuing the world’s ecosystem services and natural capital gained widespread attention [6][7]. Anan (2000) called for a Millennium Ecosystem Assessment (MEA) by submitting a report to the UN General Assembly entitled “We the Peoples: The Role of the United Nations in the 21st Century” [1]. In 2001, the MEA was initiated under the auspices of the United Nations. The MEA purposely did not focus on valuing ecosystems, but rather on the complex relationships between ecosystems and human well-being (Figure 1).
MEA (2005) found, that human pressures have changed ecosystems rapidly over the past 50 years. These changes to ecosystems have provided gains to human well-being and economic development, but at the expense of the ecosystems and that reversing the degradation of ecosystems is possible but involves significant changes in policies and practices that are not currently being undertaken. These changes can be achieved by recognising the importance of ecosystem services. MEA (2005) categories ecosystem services as follows: supporting, provisioning, regulatory and cultural.

The Economics of Ecosystems and Biodiversity Group (2010) emphasized the global economic value of biodiversity; this can assist decision makers in determining the monetary value of ecosystems.

2.2. Ecosystem Services and Sediment Management
Historically, the construction of water infrastructure projects involving dredging has been an essential activity in a country’s development and prosperity. This is even more prevalent today with the continuous growth of trade, resulting from increased prosperity and world population growth. Marine infrastructure projects can be disruptive to the environment. As a result, society’s response has been to evaluate the impacts of dredging on the environment. This has led to international and national legislation being developed such as the Habitats Directive [16] and the Water Framework Directive [17] in Europe. In general legislation is becoming more stringent for environmental protection, which can negatively impact on the implementation of innovative solutions for sediment management projects.

The dredging industry has recognised this worldwide shift towards sustainability with PIANC (2008) leading the way for the dredging industry demonstrating the importance of understanding the natural system and using natural processes to achieve a sustainable project. De Vriend & Van Koningsveld (2012) illustrated real examples of ‘Building with Nature’ solutions to sediment management projects [9]. Bridges et al. (2014) illustrated examples of successful ‘Engineering with Nature’ sediment management projects with the United States Army Corps Engineers presenting further case studies [3][44]. Further guidance on achieving sustainability in dredging projects while adding value to the natural and socio-economic system has recently been presented [5].
Maintenance of a port’s navigable areas is key to facilitating the international trend to larger ships and an increasing import-export shipping trade. In a market economy, the assets of a port are appraised in terms of job creation, GDP and import-export trade [24]. Most ports operate at the mouth of an estuary where there is typically an abundance of ecosystems. It may be stated that these ecosystems were previously classified, in general, as without ‘economic good’. The challenge that the dredging industry faces is assessing the economic value of ports with the economic value that ecosystems provide. This is where the concept of ecosystem services becomes an important contributor, where the benefits that humans derive from ecosystems can be quantified in monetary terms. By taking an ecosystem services approach towards sediment management projects, stakeholders have the opportunity to develop innovative and sustainable sediment management strategies such as ‘Building with Nature’ solutions.

The concept of taking an ecosystem services approach to a sediment management project is developed in this paper. An ecosystem services assessment is an important contributor in undertaking a full analysis of different sediment management options. Ecosystem services can contribute to ensuring that the analysis for a dredging project is sustainable and that the project is implemented satisfactorily in an environmentally sensitive location. The objective of an ecosystem services approach is to classify, outline and assess the monetary benefits that society derives from ecosystems. The benefits that humans derive from ecosystems are delivered in sediment management projects, but these benefits may not be considered as providing an economic good by the project stakeholders. An ecosystem services assessment provides quantifiable economic results which can be included as a key part of an overall assessment of a sediment management project.

3. Application of an Ecosystem Services Approach

3.1. The General Framework

In order to determine the positive and negative monetary values that humans derive from ecosystems, previously defined as ‘ecosystem services’, the unit cost (€/hectare/year) of the ecosystem is combined with the change in the land use (hectare). The change in land use refers to the positive/negative change in an ecosystem area that results from the activities associated with the development. The calculation of the ecosystem services in monetary terms, can then contribute to a full analysis for the different sediment management options for a dredging project. This paper focuses, in particular, on the ecosystem services aspect of a sediment management project.

It should be noted that the most suitable sediment management option for a dredging project is generally based on a cost-benefit analysis of the proposed options and the ecosystem services assessment typically may not feature. The methodology and application developed in this paper addresses this by undertaking an ecosystem services assessment as shown in Figure 2.

3.2. Assessment Methodology

Figure 2. Ecosystem Services Assessment – Methodology.
This section provides greater detail on the methodology used for calculating the ecosystem services value for a sediment management project. There are five general steps in the ecosystem services assessment.

Step 1 involves inputting the site-specific details including the site location, physical characteristics of the sediment and contamination levels of the sediment. The physical characteristics and contamination levels dictate the potential amount of sediment available for beneficial use.

Step 2 involves selecting the sediment management options to be assessed. This typically involves selecting a number of beneficial use options and often including the traditional disposal at sea option.

Step 3 involves identifying the categories of habitats potentially impacted by the sediment management project and quantifying the change in land use for these impacted habitats. The category of habitat typically found in dredging projects include: offshore, at shore, estuary, rivers, artificial structures, hard substrate and terrestrial. In Ireland, for example, the category of habitats is publicly available as GIS files through the National Parks and Wildlife Service website [27]. The change in land use can be quantified (hectares) by comparing the current situation against the proposed sediment management option. This step is critical to the accuracy of the ecosystem services assessment as the land use change is combined with the unit cost (Step 4) to determine a monetary value (Step 5).

Step 4 involves sourcing the relevant unit costs associated with an ecosystem service, in terms of the value that these ecosystems provide to humans. Unit costs for this paper were primarily found from national [14] and international sources [25].

Step 5 involves undertaking a quantitative (monetary) and qualitative assessment of the ecosystem services for each sediment management option. The changes in land use (in hectares) multiplied by a unit cost (€/hectare/year) allows a monetary value to be assigned to the benefits that humans derive from ecosystems as €/year.

\[ Ecosystem\ Services = Change\ in\ Land\ Use\ (Hectares) \times Unit\ Cost\ (€/hectare/year) \]

4. Ecosystem Services Assessment – An Application to a Harbour Development

An ecosystem service assessment is initially applied in a preliminary analysis for a specific ‘Building with Nature’ type sediment management option for a harbour development project, assumed to be undertaken in Ireland. The aim is to investigate the impact on ecosystem services when comparing a ‘Building with Nature’ sediment management option to the widely practiced approach of unconfined disposal at sea.

The sediment management project is assumed to involve dredging 140,000m³ of dredge material, clean and uncontaminated. The project assumes extending an existing quay structure, deepening berthing pockets for ships and construction of an adjacent amenity area. 90,000m³ of this is assumed to be fine-grained material with the remaining 50,000m³ being rock. A suitable wetland creation site is assumed as a sediment management option and located 3km sail distance from the dredging site. The project beneficially uses an assumed 50,000m³ of rock for harbor reclamation works, with disposal of 90,000m³ of fine-grained sediment to sea. For the ‘Building with Nature’ approach the 90,000m³ of fine-grained sediment is assumed suitable for placement at the wetland site with an average depth of fill of 1m. This gives an area of wetland of 90,000m² or 9ha.

An ecosystem services analysis is then applied based on the approach presented in Section 3. Table 1 and Table 2 present the results of the ecosystem services assessment for the Disposal at Sea and Wetland Creation sediment management options, respectively. The ‘Category’ heading refers to the category of habitat. ‘Habitat’ refers to the habitat type affected either negatively or positively by the dredging project. ‘Change in land use’ is the change (positive or negative) in terms of hectares that the dredging project has impacted on the specific habitat type. The ‘Total’ is the sum of all the ecosystem services affected by the change in land use for a specific habitat type. The ‘Overall Effect’ is a qualitative summary of the effect that the dredging project has on a specific habitat type.
The disposal at sea option yields a negative overall value of -€191,878/year (Table 1). Table 1 shows that the overall result is mainly impacted by the Subtidal Deep habitat. A change in land use of -11.43 hectares occurs as a result of the existing quay structure seaward extension as part of the development and thus having a negative impact on this habitat type.

The Wetland Creation option results in a positive overall value of €1,403,275/year (Table 2). It can be seen from Table 2 that the +9 hectares of land use for the bare tidal flat main impacts on the overall result. The +9 hectares is created using 90,000m³ of sediment and with fill depth placement of 1m at the relocation site to create the wetlands.

To put the results from the ecosystem services assessment in context, a direct cost analysis of such a harbour development project was carried out using an economic model developed by Munster Technological University [20][21]. The direct cost of the sediment management project is approximately €6.3m and €7.6m for the wetland creation and unconfined disposal at sea options, respectively.

### Table 1. Indicative Ecosystem services Results - Disposal at Sea Option.

| Category     | Habitat            | Change in land use (ha) | Total Overall Effect (€/y) | POS/NEG |
|--------------|--------------------|-------------------------|----------------------------|---------|
| Shore        | Beach              | -0.86                   | -1,197                     | NEG     |
|              | Estuary            | Subtidal deep           | -11.43                     | -193,478| NEG     |
|              | Bare Tidal Flat    |                         |                            |         |
| Artificial Structures | Artificial reefs  | 1.74                    | 1,570                      | POS     |
| Hard Substrate | Rock Rubble       | -0.71                   | -641                       | NEG     |
| Terrestrial  | Dunes, Planted Area| 0.16                    | 424                        | POS     |
|              | Grassland          | 0.5                     | 1,444                      | POS     |
| Summary      |                    |                         | -191,878                   | POS/NEG |

### Table 2. Indicative Ecosystem services Results – Wetland Creation Option.

| Category     | Habitat              | Change in land use (ha) | Total Overall Effect (€/y) | POS/NEG |
|--------------|----------------------|-------------------------|----------------------------|---------|
| Shore        | Beach                | -0.86                   | -1,197                     | NEG     |
|              | Estuary              | Subtidal deep           | -11.43                     | -193,478| NEG     |
|              | Bare Tidal Flat      |                         |                            |         |
| Artificial Structures | Artificial reefs  | 1.74                    | 1,570                      | POS     |
| Hard Substrate | Rock Rubble       | -0.71                   | -641                       | NEG     |
| Terrestrial  | Dunes, Planted Area  | 0.16                    | 424                        | POS     |
|              | Grassland            | 0.5                     | 1,444                      | POS     |
| Summary      |                      |                         | 1,403,275                  | POS/NEG |

### 5. Discussion and conclusions

This paper presents an ecosystem services approach that may be applied to assess sediment management scenarios for dredging projects providing an additional important contribution to informing the decision-making process in selecting the most sustainable sediment management option. This ecosystem services approach demonstrates the potential to quantify the monetary effects (both positive and negative) that ecosystem services provide for a sediment management project.

The application of an ecosystem services approach is applied in this paper to a harbour development project, assumed to be undertaken in Ireland, where two different sediment management scenarios are analyzed. The first scenario is the widely practiced unconfined disposal at sea approach and the second scenario is a ‘Building with Nature’ solution in the form of wetland creation. This approach is consistent with the European Union’s (EU) adoption of a ‘Circular Economy Action Plan’, which aims to help close the loop of product lifecycles through greater re-use, bringing benefits both for the environment and the economy [15].

The analysis and application of ecosystem services to ‘Building with Nature’ solutions contributes to potentially ensuring more sustainable use of a natural resource in the form of dredged material in the
context of the principles of the circular economy. Indicative results from the analysis presented in this paper show the positive ecosystem services monetary value where the sediment is beneficially used. This ecosystem services approach may also contribute to sediment management permitting policy and practice. For example the Irish regulator for assessing dredged material disposal at sea applications is the Environmental Protection Agency (EPA). Ireland and similar to many other countries requires an assessment of the sediment management alternatives to disposal at sea as part of the permitting process. This paper illustrates the value of undertaking an ecosystem services assessment where beneficial use of sediment is considered as a project option. The inclusion of such an assessment as part of the permitting process would enhance the potential for application of innovative ‘Building with Nature’ approaches, potentially reducing dredge sediment quantities disposed at sea. This research work is continuing with a range of other ‘Building with Nature’ type sediment management techniques being assessed in the context of ecosystem services including, for example, beach nourishment and dike construction and with application to specific sites in Ireland.

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