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Setting limits for acceptable change in sediment particle size composition: Testing a new approach to managing marine aggregate dredging

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ABSTRACT

A baseline dataset from 2005 was used to identify the spatial distribution of macrofaunal assemblages across the eastern English Channel. The range of sediment composition found in association with each assemblage was used to define limits for acceptable change at ten licensed marine aggregate extraction areas. Sediment data acquired in 2010, 4 years after the onset of dredging, were used to assess whether conditions remained within the acceptable limits. Despite the observed changes in sediment composition, the composition of sediments in and around nine extraction areas remained within pre-defined acceptable limits. At the tenth site, some of the observed changes within the licence area were judged to have gone beyond the acceptable limits. Implications of the changes are discussed, and appropriate management measures identified. The approach taken in this study offers a simple, objective and cost-effective method for assessing the significance of change, and could simplify the existing monitoring regime.

1. Introduction

The UK marine aggregate dredging industry provides sand and gravel to domestic and European customers for construction and coastal defence (Highley et al., 2007). Material is extracted from the seabed using purpose-built dredging vessels, with operations taking place within 70 licensed areas located around the coast of England and Wales (Russell, 2011). In some locations, aggregate dredging has been shown to alter the composition of seabed sediments (e.g. Dickson and Lee, 1972; Kenny and Rees, 1996; Kenny et al., 1998; Newell et al., 1998, 2004a; Boyd et al., 2002; Cooper et al., 2007). Such changes can occur in a variety of ways (see Newell et al., 1998), although a major cause is associated with sediment screening (Poiner and Kennedy, 1984; Hitchcock and Drucker, 1996; Newell et al., 1998, 2004a), a process used to modify the composition of dredged cargoes, resulting in the return of unwanted sediment fractions, normally sands, to the seabed.

Research suggests that changes in the composition of seabed sediments can affect the ability of a site to recover, in terms of the benthic fauna, to a pre-dredge state post-dredging (Desprez, 2000; Newell et al., 2004a,b; Boyd et al., 2005; Robinson et al., 2005; Desprez et al., 2010; Cooper et al., 2011b,c; Barrio Froján et al., 2011; Wan Hussin et al., 2012). The composition of seabed sediments is also important for other components of the ecosystem including herring spawning success (de Groot, 1980). To mitigate the effects of dredging, conditions are often applied to extraction licences. Examples of licence conditions include: (1) limits on the extraction rate; (2) limits on the total tonnage extracted; (3) restrictions regarding the quantity of material which can be screened; (4) a requirement to leave the seabed in a similar physical condition after dredging; and (5) a requirement to monitor the environmental effects of dredging over the licence term (see Ware and Kenny, 2011).

The challenge for both the developer and the regulators is identifying, from the monitoring programme, what constitutes unacceptable environmental change. The reason this can be difficult is that monitoring looks at changes in response to ongoing dredging with, typically, little or no information about how long effects will last (i.e. recoverability). Despite some efforts (see Foden et al., 2009; MESL, 2007), knowledge of recovery times is still partial. In addition, our understanding of the wider significance of localised environmental change is not well understood (e.g. Kenny et al., 2010; Daskalov et al., 2011). For these reasons, decisions regarding acceptability of change are typically based on expert judgement. Whilst the licence condition requiring sediments to be left in 'similar' physical condition (ODPM, 2002) is sensible, given the implications for faunal recovery, the subjective nature of the term 'similar' means that the condition is of little practical use (Cooper et al., 2011a). If government policy makers, regulators

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and industry are to achieve their shared goal of sustainability (BMAPA, 2006; UK Marine and Coastal Access Act, 2009) there needs to be a better way of differentiating between acceptable and unacceptable environmental change.

A possible solution to this problem was recently proposed in Cooper (2012). His approach works by identifying the range of sediment particle size composition naturally found in association with the pre-dredge faunal assemblage(s) in the wider region. Theoretically, as long as sediment composition within areas of impact remains within this range, which can be specified as a licence condition, then it should be possible for a return of the pre-dredge faunal assemblage after cessation of dredging. This approach offers a number of advantages:

1. It has a clear scientific rationale, with the aim of maximising the sustainability of marine aggregate dredging.
2. The local environment is used to define the limits of acceptable change. This is important given results in Cooper et al. (2011b) which showed that benthic faunal communities are not uniformly sensitive to changes in sediment composition, with lower sensitivity in high energy sandy areas, and higher sensitivity in low energy, gravel areas.
3. It allows for change in sediment composition as a result of dredging. This is important given that some degree of change is highly likely given that targeted resource deposits are rarely, if ever, uniform in composition.
4. As changes in sediment composition are easily measurable, this means that it should be clear when conditions are not within acceptable limits, allowing for an appropriate management response (see Cooper, 2012).
5. It has the potential to reduce the costs of monitoring programmes by focusing on sediments rather than macrofauna.

With the above approach, there is still a need to understand the capacity for physical and biological recovery. In addition, there will continue to be a need to monitor the macrofauna at context stations (within areas outside the predicted effects of dredging). These areas are likely to have an important role in the recolonisation of dredged areas upon cessation of dredging, and for allowing the regulator to assess whether the level of anthropogenic pressure in the region is sustainable (see Barrio Froján et al., 2008).

A trial of this new approach to the setting of acceptable limits of change in sediment composition was undertaken using data from an extraction site off Hastings on the south coast of the UK. This study (Cooper, 2012) showed that sediments within the licence area remained within a pre-defined acceptable range. The expected faunal recovery potential of the site was confirmed by results in Cooper et al. (2007), who reported a 7 year recovery time within areas of low dredging intensity. Given the advantages of the approach, it was concluded that it should be considered for use in the regulatory context. However, before this could happen, there was an obvious need for further testing and refinement of the method.

The aim of the present study was to test the approach in the eastern English Channel (EEC), a region containing ten aggregate extraction areas. The EEC was chosen due to the availability of extensive baseline and monitoring datasets, and a desire on the part of the developers to review the existing monitoring regime (ECA, 2011). Specific objectives were to: (1) Identify, characterise and map the broadscale distribution of macrofaunal assemblages present in the survey area; (2) Identify the range of sediment particle size composition found in association with each assemblage; (3) Identify the macrofaunal assemblage(s) present within each of the extraction sites, and their associated zone of potential secondary effects; (4) Identify a suitable licence condition for acceptable change in sediment composition for each licensed area; and (5) Assess compliance with the stated condition using the most recently available monitoring data from 2010, 4 years after the start of dredging operations.

2. Methods

2.1. Data

The baseline dataset used in this study came from the 2005 Eastern English Channel Regional Environmental Assessment (REA) survey (ECA and EMU Ltd., 2010a, 2010b). This survey included 458 samples for macrofauna and sediments. Macrofaunal samples were processed over a 1 mm sieve, and the resulting data included countable, and non-countable colonial taxa. The sediment particle size data were supplied as percentage weight by size class (<0.063 mm, 0.63 mm, 0.125 mm, 0.25 mm, 0.5 mm, 1.0 mm, 2.0 mm, 4.0 mm, 8.0 mm, 16.0 mm, 32.0 mm, ⩾64.0 mm). Whilst other baseline benthic datasets from the region were available (e.g. James et al., 2007; ECA and Emu Ltd., 2010c, 2010d), issues of comparability precluded their use. Monitoring data from 2010 (ECA and EMU Ltd., 2010e) included 427 sediment samples, and these data were used to assess for change in sediment composition after 4 years of dredging. Samples from both surveys were acquired using a 0.1 m^2 Hamon grab, and were processed in a comparable way (see Ware and Kenny, 2011). The location of baseline and monitoring stations is shown in Fig. 1.

2.1.1. Treatment categories

All samples were assigned to one of the following treatment groups, depending on their location:

Primary Impact Zone (PIZ). Samples taken from within the licence boundary, and which may or may not have been subject to the direct effects of dredging.

Secondary Impact Zone (SIZ). Samples taken outside the PIZ, but within a full tidal excursion of the licence boundary. The SIZ is subdivided into *near-field* (within 2.5 km of the licence boundary), and *far-field* (>2.5 km to the full tidal excursion) zones. Samples intersecting more than one SIZ were also assigned to a 'cumulative' category.

Reference. Samples taken from stations located beyond the predicted effects of dredging (i.e. outside the PIZ and SIZ). This category includes samples taken from within defined references boxes, or positioned throughout the remainder of the survey area, so-called 'context' samples.

2.2. Baseline faunal assemblage distribution

A map of baseline faunal assemblage distribution was produced following a similar approach to that set out in Cooper (2012). However, the approach taken in the present study differed in two respects. Firstly, colonial taxa were included in the faunal dataset due to their local importance. The influence of colonial and rarer taxa in subsequent data analysis was assured by initially subjecting data to a fourth-root transformation (see Clarke and Green, 1988). Secondly, clustering of the benthic dataset was performed in R (R Development Core Team, 2010) using the k-means R function available from the *flexclust* library. The k-means method works by finding a solution that minimises the within cluster sum of squares for the *i*th species, summed over all species. The Hartigan and Wong (1979) algorithm was used to find solutions based on different numbers of pre-defined cluster groups. Maps were produced of faunal assemblage distribution based on different numbers of cluster groups. A decision was made as to the appropriate number of