MONITORING AND ASSESSMENT OF THE MARINE ENVIRONMENT

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

Submitted by the United Kingdom

SUMMARY

Executive summary: This document contains a summary of the testing of an approach to setting the limits of acceptable change in sediment particle size at worked out marine aggregate extraction sites

Action to be taken: Paragraph 5

Related document: LC/SG 37/INF.14

Introduction


2. Further to the approach set out in document LC/SG 37/INF.14, 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, four 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.

This document may be of some interest in relation to the monitoring of dredged material disposal sites.

**Action requested of the Scientific Groups**

The Scientific Groups are invited to note the information provided and comment, as they deem appropriate.
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.

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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 (Pinder 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 sand, to the seabed.

Research suggests that changes in the composition of seabed sediments may affect the ability of a site to recover, in terms of the benthiic fauna, to a pre-dredge state post-dredging (Desprez, 2006; Newell et al., 2004a,b; Boyd et al., 2005; Robinson et al., 2005; Desprez et al., 2010; Cooper et al., 2011b; Barito Frojan 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 Fedak 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
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 sedi-
ment particle size composition naturally found in association with the pre-dredge faunal assemblage(s) in the wider region. Theoret-
ically, as long as sediment composition within areas of impact re-
mains 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 pro-
grammes 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 sta-
tions (within areas outside the predicted effects of dredging). These areas are likely to have an important role in the recognisation of
dredged areas upon cessation of dredging, and for allowing the reg-
ulator to assess whether the level of anthropogenic pressure in the region is sustainable (see Barron 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 fau-
nal 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 BMU Ltd., 2010a, 2010b). This survey in-
cluded 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, 0.063 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 BMU 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 ac-
quired using a 0.1 m² Hamon grab, and were processed in a com-
parable 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 di-
rect 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 sub-
divided into near-field (within 2.5 km of the licence boundary), and
far-field (>2.5 km to the full tidal excursion) zones. Samples inter-
secting more than one SIZ were also assigned to a 'cumulative'
category.

Reference. Samples taken from stations located beyond the pre-
dicted effects of dredging (i.e. outside the PIZ and SIZ). This cat-
eger includes samples taken from within defined reference
areas, 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). How-
never, the approach taken in the present study differed in two re-
pects. 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 avail-
able from the fclust library. The k-means method works by find-
ing a solution that minimises the within cluster sum of squares for
the ith species, summed over all species. The Hartigan and Wong
(1979) algorithm was used to find solutions based on different numbers
of predefined cluster groups. Maps were produced of fa-
unal assemblage distribution based on different numbers of cluster
groups. A decision was made as to the appropriate number of
cluster groups based on a desire to maximise the level of ecological information, whilst ensuring a sufficient number of sample replicates to support subsequent data analysis.

2.3. Baseline faunal assemblage characteristics

The number of taxa (including colonials) and the number of individuals was determined for each macrofaunal sample. These data were used to calculate mean values for each faunal assemblage. A bar chart, showing 95% confidence intervals, was used to examine the difference in both metrics between the different assemblages. The SIMPER routine in Primer (Clarke and Warwick, 1994) was used to identify the characterising taxa from each assemblage.

2.4. Baseline sediment characteristics

Plots of sediment particle size distribution (cumulative weight by sediment size class) were used to compare the sediment composition of samples belonging to each of the identified faunal assemblages. For each assemblage, the mean and upper and lower limits of the cumulative distribution were also plotted. The upper and lower limits, also termed the 'sediment envelope', were simply the highest and lowest values for each sediment size class.

Using the cumulative sediment data, the percentages of major sediment fractions (coarse gravel, medium gravel, fine gravel, coarse sand, medium sand, fine sand, silt/clay) were calculated for individual samples. Sediment fractions were based on the Wentworth classification (Wentworth, 1922). Using these summary data,
the mean, and the upper and lower limits were again determined. As before, the upper and lower limits were simply the highest and lowest values for each size class. These values defined the range of sediment composition found in association with each faunal assemblage, and hence the upper and lower limits of acceptable change within extraction areas and their zones of potential secondary effect. Clearly, the full range of sediment composition found in association with each faunal assemblage is more likely to be identified with higher numbers of samples. This fact should provide a powerful incentive to the aggregates industry to acquire more rather than less samples at the baseline characterisation stage.

An ANOSIM test (Clarke and Warwick, 1994) was applied to the same summary dataset to determine whether there were statistically significant differences in the sediment composition of samples belonging to the different faunal assemblages. The R value from this test provides a measure of the difference between groups, and would be expected to be in the range from zero to one; a value of zero implies there is no difference between groups, whilst a value of one implies that groups are completely different; an associated p-value of < 0.05 was taken to imply statistical significance. The SIMPER routine in Primer was used to identify which sediment fractions accounted for the differences between faunal cluster groups.

2.5. Licence condition

It is proposed that the following standard condition would be applied to all licences:

At the end of the licence term, and with allowance made for natural variability, the composition of sediments within the Primary and Secondary Impact Zones must remain within the acceptable change limits for the faunal groups identified during the pre-dredge survey. Compliance will be established using the methodology outlined in this paper.

The aim of this condition is to ensure that the seabed habitat is maintained in a state that will allow for the return of the pre-dredge faunal distribution after dredging, thus ensuring the long-term sustainability of marine aggregate dredging on seabed macrofaunal communities.

2.6. Survey design

The adequacy of the existing survey design was assessed using statistical power analysis. Specifically, the analysis was used to identify the level of difference in the mean composition of each sediment fraction which might be reliably detected between the baseline and monitoring surveys. This assessment was made for each treatment (e.g. PIZ, SIZ and REF), both at the level of individual extraction site, and using all the data. Analyses were undertaken in Minitab v15 using the Power and Sample size calculator for a two-sample t-test. The test required input variables for standard deviation (s), required statistical power (1 − β), and the number of samples available (n). Standard deviation was based on the differences in each sediment fraction between the baseline and monitoring surveys. A power of 0.8 was chosen so that there was a relatively high chance that a difference, if present, would be detected. The number of samples (n) was the number of sites where both a baseline and a monitoring sample were available for comparison.

2.7. Assessing for gross changes in sediment composition

Major changes in sediment composition were identified for all locations (PIZ, SIZ and REF), both at the individual site and meta-analysis level, using a paired sample t-test. Tests were performed in Microsoft Excel, with the null hypothesis that the mean (μ) of each sediment fraction was the same before and after dredging. As the difference could be in either direction, a two-tailed test was applied. A p-value of < 0.05 was taken to indicate a potential statistically significant difference in the means of the two groups, leading to a rejection of H0.

2.8. Assessing compliance with the licence condition for acceptable change

A series of line charts, one for each of the identified faunal cluster groups, was produced for the PIZ and SIZ of each extraction area and the Reference sites. The line charts showed the major sediment fractions (coarse gravel, medium gravel, fine gravel, coarse sand, medium sand, fine sand, silt/clay) along the x-axis, and percentage contribution along the y-axis. Onto these charts were plotted the relevant upper and lower acceptable change limits (see Section 2.4), and the individual monitoring samples data. Where the value of a sediment fraction for any individual sample fell outside the upper or lower limits, this was termed a ‘deviation’. Compliance with the stated licence condition for acceptable change was established for both PIZ and SIZ by comparing the total number of deviations versus the total number of possible deviations (see equation below). The number of possible deviations is simply the number of samples (n) multiplied by the number of sediment fractions (i.e. seven).

\[
\%\:\text{Compliance} = 100 - \left(\frac{\text{No. of observed deviations}}{\text{No. of possible deviations}}\right) \times 100 \tag{1}
\]

Changes in either zone (PIZ/SIZ) were deemed acceptable where the percentage compliance was within the range seen for individual reference sites. Where the percentage compliance was less than that observed for any of the reference sites, the site/zone was deemed non-compliant. Analyses were undertaken to assess for change and compliance at individual sites and, using data pooled by treatment categories (PIZ, SIZ and Reference), for the region as a whole.

2.9. Addressing non-compliance

Where a site was deemed to be non-compliant, three further steps followed. Firstly, the likely consequences of the deviations were considered (i.e. what eventual changes in faunal group might result from the altered sediment composition?). This assessment was made using a further line chart showing the individual sample deviations and the upper and lower limits of acceptable change in sediment composition for all faunal cluster groups. On this chart, individual sample deviations were identified using a cross symbol coloured according to the original baseline faunal group. Next, the location of the sample(s) where problem deviations occurred was identified. This allowed the spatial scale of the problem to be observed. Finally, an appropriate management response was identified. What constitutes an appropriate response will vary, but options include the following: do nothing (where natural recovery is expected), reduce extraction rate, target extraction of the problem sediments, change screening practices.

3. Results

3.1. Baseline faunal assemblage distribution

A cluster iteration based on four different faunal assemblages (A–D) was taken forward in the subsequent analysis. Whilst there was clearly some overlap in the distribution of these assemblages, there was a clear transition from group A to group D moving from
the west-south-west to the east-north-east of the survey area (Fig. 2). With the exception of the PIZ of Area 474/3, the PIZ and SIZ of all extraction sites and reference areas contained at least two different faunal assemblages.

3.2. Baseline faunal assemblage characteristics

3.2.1. Univariate summary measures

A comparison of the mean number of taxa and individuals revealed clear differences amongst the different faunal assemblages (Fig. 3). The lowest mean number of taxa and individuals was associated with samples from faunal assemblage D. In comparison, cluster groups A, B and C had much higher values of both measures. Of these three groups, faunal assemblage B had the highest values, with similar levels of both measures seen for assemblages A and C.

3.2.2. Species composition

Values of Bray–Curtis similarity showed that samples associated with faunal assemblage D were quite different to all other groups (values were 23% for B, 26% for A, and 28% for C). Values of similarity between groups A, B and C were much higher at ~50%, particularly for groups A and B.

The results of a SIMPER analysis (Table 1) revealed that certain taxa were characteristic of all faunal cluster groups. These taxa included the ribbon worm NEMERTEA, the polychaete Aonides pectinibranchia, and the bryozoan Choristopora brongniartii. However, differences were also apparent between the different assemblages. For example, A and B were dominated by taxa that are typical of gravel-rich sediments. These include the crustaceans Golefeia intermedia (squat lobster) and Apherusa biplinea, polychaetes Pomoceros spp. (Keel worm) and Lancois bulbicenus, and the echinoderm Amphiphis squamata. A comparison of the species found in association with both these groups suggests that A could be regarded as a slightly more impoverished version of B. Whilst sharing some of the species typically associated with coarser sediments, cluster group C also included species more typical of sandy sediments; for example, the echinoderm Echinocystis pusillus, and the polychaete Glycera elegans (agg). In addition to the ubiquitous taxa, cluster group D included species typical of sandy sediments:

Fig. 3. Mean and 95% confidence intervals for: (a) number of taxa (colonial taxa included), and (b) number of individuals for faunal assemblages A–D. Figures below the bottom graph show the number and proportion of samples belonging to each assemblage.

Fig. 2. Distribution of faunal assemblages (A–D) identified through a cluster analysis of the 2005 baseline macrofaunal dataset.
3.3. Baseline sediment characteristics

The cumulative sediment distribution plots show some obvious differences in the composition of samples belonging to the different faunal assemblage groups (Fig. 4). For example, gravel makes up a significant component of the sediment composition of samples associated with groups A and B. The majority of these samples would, according to the Folk classification (Long, 2008), be described as sandy gravels. These assemblages account for the majority (61%) of baseline samples. In contrast, sand was the dominant sediment fraction associated with group D. These samples account for 10% of the baseline samples, and included gravelly sands, slightly gravelly sands and sands. In addition, there were a small number of sandy gravels belonging to this group. Samples belonging to group C account for 29% of the baseline samples, and included similar numbers of sandy gravels and gravelly sands. The proportion of silt/clay in all assemblage groups was generally low, around 1%, or less, although higher amounts were occasionally found in association with groups A, B and D. For each assemblage group, the inset tables in Fig. 4 give the mean and upper and lower limits for the sediment distribution based on major sediment classes. These limits define the known and therefore acceptable range of sediment composition for each assemblage.

Sediments associated with assemblage D were quite different ($R > 0.5, p < 0.05$) from all other groups (see Table 2). These differences resulted largely from the higher proportion of medium sand, and lower proportion of coarse sand and gravel fraction compared to the other groups. Differences between sediments from group C with those from groups A and B are explained by the higher proportion of coarse sand found in association with group C. Differences between groups A and B, although minimal, are explained by the higher proportion of coarse gravel for group B.

3.4. Survey design

Power analysis shows that there were differences between sites in terms of the level of difference in mean sediment composition that can be detected (Table 3). These differences are a result of the differences in the number of samples between sites, and differences in the variability of each sediment fraction within individual sites.

3.5. Assessing for gross changes in sediment composition

Meta-analysis, using data from all sites, revealed a statistically significant increase in fine sand and silt/clay, and a decrease in fine gravel within the PIZ treatment. The increase in silt/clay was also observed in the SIZ treatment, combined with a decrease in coarse sand. Meta-analysis suggests that the increase in silt/clay was greater in the near-field zone (i.e., within 2.5 km of the licence boundary) (see Table 3). This observation is consistent with an impact associated with dredging.

Inspection of individual licences (Table 3) revealed that the increase in fine sand within the PIZ treatment was restricted to two sites, Area 474/2 and Area 461. However, all sites showed significant increases in the proportion of silt/clay within the PIZ. Statistically significant changes in sediment composition within the SIZ were only observed for four of the seven dredged extraction areas (Areas 474/1, 474/2, 473/2 and 461). The increase in silt/clay observed in two of the five Reference boxes, and the PIZ and SIZ of the non-dredged licences suggests there may be a non-dredging.
Table 1
Results of a SIMPER analysis showing the characterising species from each faunal assemblage (A–D) accounting for 60% of the within-cluster similarity. Analyses were based on fourth-root transformed macrofauna abundance data (colonial taxa included).

<table>
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<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
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Table 2
Results of an ANOSIM test based on un-transformed sediment data (% coarse gravel, % medium gravel, % fine gravel, % coarse sand, % medium sand, % fine sand and % silt/clay).

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<th>p-Value</th>
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<td>D vs C</td>
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<td>B vs A</td>
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</table>

possibly natural, component to this increase. Evidence for this is particularly natural at Reference site 1, where residual currents would be expected to take sediment in an east-north-east direction (ECA, 2011). However, the almost universal increase in silt/clay within PIZs where dredging has taken place suggests at least some of the increase is associated with aggregate dredging. No statistically significant changes in sediment composition were found for samples assigned to the ‘cumulative’ category.

3.6. Assessing compliance with the licence condition for acceptable change

The sediment composition of the majority of monitoring samples fell within the relatively upper and lower acceptable limits, with relatively few deviations (see example area shown in Fig. 5). Overall, values of percentage compliance were within the range seen at reference sites for the PIZ of nine extraction sites, and the SIZ of all ten sites (Table 4). This means that were dredging to have stopped following completion of the monitoring survey in 2010, then these compliant areas should have been able to support a return of the original faunal assemblages, allowing for natural changes. The only site where percentage compliance was outside the reference site values was the PIZ of Area 473/2. The non-compliance at this site is considered further below.

3.7. Addressing non-compliance

3.7.1. Implications

A detailed assessment of the sediment deviations observed within the Area 473/2 PIZ is shown in Fig. 6. Despite taking the sediment composition outside the range for group A (deviations 1, 2, 3 and 5), the altered values remain within the range of acceptability for assemblage group B. As group B is considered a richer version of group A (see Section 3.2.2), such changes could be considered acceptable. In contrast, deviations 4 and 6 take the sediments in the opposite direction (i.e., outside the acceptable limits for group B, but inside for group A). Clearly this is less desirable, but given the similarity between groups A and B, and the localised nature of the deviation, such changes are of major concern. This leaves deviations 7 and 8. For 7, the higher silt/clay levels are outside the limits for assemblage group C. However, as evidence suggests such changes may be associated with a non-dredging origin, it is sensible to not be too concerned about this. In contrast, deviation 8 takes sediments in the direction of group A to group D. This is of concern as D supports a much reduced faunal assemblage compared to all other assemblage groups.

3.7.2. Location

Deviation 7 occurred at monitoring site 102, located within the eastern end of the PIZ of Area 473/2.

3.7.3. Management action

Research undertaken at 473/2 (ECA, 2011), which acts as a proxy for other licences in the region, has shown that areas of line sediment accumulation should naturally disperse once dredging ceases, or the rate of extraction drops below a certain threshold level. Given this understanding, the appropriate management response would, at this stage, be to do nothing other than to continue to monitor the situation. Were subsequent monitoring to show that the situation had persisted or worsened then it may be sensible to review this decision.

4. Discussion

4.1. Major findings

In this study, four faunal assemblages were identified within the Eastern English Channel. The range of sediment composition found in association with each of these groups was used to define limits for acceptable change in areas influenced by aggregate dredging. Results of a comparison of baseline and monitoring data from 2010 showed evidence of changes in sediment composition,
both as a result of dredging and non-dredging related factors. Despite the changes, the composition of sediment within the PI2 and SIZ of all sites, with exception of the PI2 of Area 473/2, remained within the acceptable limits. A detailed assessment of the sediment deviations at Area 473/2 suggests the problem was confined to elevated levels of fine sand at one station. Given the transient nature of such features (see below), no further intervention was deemed necessary, other than for continued monitoring.

### 4.2. Importance of findings

The results of this study are important as they suggest that were dredging to have ceased immediately after the 2010 monitoring survey, the composition of sediments would not, in all but the PI2 of Area 473/2, have presented a barrier to full benthic faunal recovery. In addition, the approach to assessing change makes it possible to differentiate between statistically and ecologically significant change in sediment composition, without the need for subjective expert judgement.

### 4.3. Comparison with other studies

A number of aspects of the methodology employed in the present study differ from those used in the initial trial of the approach (Cooper, 2012), and these differences warrant explanation. Firstly, the epifaunal taxa from grab samples were included in the dataset as a result of their local importance in the eastern English Channel. Secondly, the k-means clustering method was employed here to allow the number of faunal cluster groups to be specified. This was necessary as the initial group average clustering of data produced an unworkable number of statistically distinct cluster groups. Thirdly, the gravel fraction was split into coarse, medium, and fine fractions. This was considered necessary given the importance of larger gravel fractions for attachment of certain species. Fourthly, the upper and lower acceptable change limits for different sediment fractions were based on the full range of values rather than a 95th percentile range as used at Hastings (Cooper, 2012). This was necessary as some of the more extreme values, which would have been excluded with a 95th percentile range, occurred within primary or secondary impact zones. Exclusion of these values from the acceptable range would have resulted in deviations even before dredging had begun; clearly this would make no sense. Finally, the approach taken for assessing compliance has changed. In the Hastings study (Cooper, 2012), compliance was established where the mean level of major sediment fractions was within the range defined by the upper and lower limits of sediment composition for the relevant faunal assemblage in the wider region. This approach has two problems. Firstly, it relies on there being an adequate number of replicates with which to assess change. Whilst this was true of the Hastings site, the present study identified multiple faunal assemblages within the PI2 and SIZ of the licensed areas. For some of these assemblages, there was little or no replication. Secondly, it is possible to imagine a situation where values of some sediment fractions might fall outside the acceptable limits, yet the mean value remains unchanged. For these reasons, a different approach to assessing compliance based on changes in sediment composition at individual monitoring stations was used. A consideration of changes in sediment composition at individual monitoring stations has the advantage of allowing the spatial extent of problem areas to be identified, allowing for targeted management intervention.

### Table 3

A detectable change limits for different sediment fractions (G = coarse gravel, M = medium gravel, F = fine gravel, C = coarse sand, M = medium sand, F = fine sand and SC = Silt/Clay). B) Changes in mean percentage composition of sediment fractions between the baseline (2005) and monitoring (2010) surveys: positive changes are shaded. Statistically significant results, based on a paired 2-sample t-test, are underlined.

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The results of this study are broadly consistent with the findings of the Eastern Channel Regional Monitoring Programme (ECRMP) (ECA, 2011). Included in the ECRMP has been an ongoing assessment of environmental change at Area 473/2, employing a range of techniques to investigate seabed condition (e.g. bathymetry, sidescan sonar, grab sampling for macrofauna and sediment particle size, photography, and sediment tracers). The extent of dredge plumes and the nature of overspill and screened material have also been assessed at this site (HR Wallingford, 2011). Area 473/2 was specifically chosen for such detailed investigation as it was considered to be representative of all extraction sites in the eastern English Channel. In addition, it was where the most intensive dredging was planned, and hence where impacts were most likely to develop. Surveys undertaken in 2007 and 2008 showed that, initially, impacts on sediment and macrofauna were confined to the Active Dredge Zone (ADZ). However, after 2 years of dredging, and following an increase in dredging intensity and the frequency of screening, impacts became apparent in the SIZ. These impacts, evident from sidescan sonar data, comprised of a thin veneer of fine sediment accumulation to the east-north-east of the ADZ and, to a lesser extent, to the south-west of the ADZ. The maximum extent of the feature extended to 2.8 km east-north-east of the licence boundary (ECA, 2011). Whilst the impact features were associated with impacts on the macrofauna, such changes were not detected elsewhere in the SIZ. Following a reduction in the intensity of dredging, these features were shown to dissipate under the action of tidal currents, and in 2010 they had disappeared altogether. The transient nature of impacts on the benthic fauna within the SIZ in this location is an important finding.

4.4. Limitations of approach

The need to specify the number of faunal cluster groups inevitably introduces a subjective element into the process, and some judgement needs to be exercised in this regard. The judgement has to balance the need to preserve the detail (i.e. maximise the number of faunal groups), whilst at the same time seeking to ensure that the likely full range of sediment composition is effectively identified for each group. As such, it may be sensible to opt for more cluster groups where the number of available samples and the spatial extent of their coverage is large, and to accept fewer cluster groups where the number of samples, or the spatial extent of their coverage is lower. For the sake of consistency, it may also be sensible for such assessments to be made by the same individual.

In contrast to the Hastings study site (Cooper, 2012; Cooper et al., 2007), very little information exists concerning the potential for faunal recovery in the eastern English Channel dredging region. As a result, the prediction that a full recovery will be possible, assuming sediments remain within the defined acceptable limits, remains a hypothesis which needs to be tested. Were sites shown not to recover, despite complying with the licence condition for acceptable change in sediment composition, then it may be necessary to adopt more a more conservative range of acceptable sediment conditions.

4.6. Implications

Given the success of the Eastern Channel Regional Monitoring Programme (ECA, 2011) in informing the understanding of dredging impacts in the region, it is sensible that the developer (Eastern Channel Association) wishes to review the existing monitoring arrangements for the next 5 years (2011–2016), to ensure that the level of effort remains proportionate to both the understanding of impacts and the level of environmental risk (ECA, 2011). From the perspective of the industry regulators, the results of the ECRMP are likely to provide confidence that the environmental impacts from dredging in the ECR are conforming to, or are less than, what was predicted in the Environmental Statements. However, the difficult issue for the regulator, in this and all extraction areas, remains one of being able to identify the point at which impacts become unacceptable. The findings of the present study have the potential to offer benefits here to both parties. For
example, the ability to assess a change in relation to pre-defined limits will allow the regulator, and their scientific advisors, to differentiate between statistical and ecological significance, and hence when management intervention is warranted (see Cooper, 2012). However, it is important to recognise that, in addition to the benthic macrofauna, other factors may influence the limits of acceptable change in sediment composition. For example, the specific requirements of benthic spawning grounds (see de Groot, 1980).

For the developer, the method may allow for a more cost-effective approach to monitoring given that approximately 90% of the cost of processing grab samples is associated with the macrofauna, with 10% for the sediments (assuming respective processing costs of £450 and £50 per sample). There are also savings in terms of reporting, as the purpose of monitoring within the PIZ and SIZ would simply be to determine compliance with the stated licence condition(s) for sediment particle size. As a result, reports will be shorter, making them quicker to produce and, ultimately, to assess.

4.7. Adoption of approach

Were a decision to be made to switch to this approach to monitoring, it is recommended that the detailed programme of investigation at Area 473/2 is continued in order to address outstanding questions concerning recovery, both within areas subject to the direct effects of dredging, and in the SIZ where fine sediments have been deposited and subsequently dissipated. In addition, it is recommended that monitoring of sediments and macrofauna within reference boxes and context stations is also continued. This work will allow the broadscale characterisation of region to be kept up-to-date, reducing the need for additional characterisation surveys in support of new licence area applications. In addition, it will provide a time series for macrofauna and sediments in the region.

Analysis of trends may help to identify if the capacity of the environment to cope with dredging, and other anthropogenic pressures in the region, is exceeded (see Barrio Frojan et al., 2008). The data could also usefully contribute to UK monitoring programmes. Asking the aggregates industry to contribute, directly or indirectly, through initiatives has some logic given that their activities, in combination with other anthropogenic pressures, may have a bearing on the status of the UK seas. The time-series would also provide a check on the health of surrounding faunal assemblages. This is important as these areas will have an important role, through provision of individuals and larvae, in the eventual recolonisation of impacted areas.

Adoption of the monitoring approach used in this study for other dredging regions in the UK is considered achievable, although some work would be required to establish appropriate baseline conditions using a combination of historic and new samples. To determine what new sampling will be required, a regular triangular grid of stations will need to be established within the PIZ and SIZ of each extraction site. The use of a regular grid will allow for better spatial coverage of the zone, resulting in an improvement ability to detect changes should they occur (see Barry and Nicholson, 1993). The required number of samples, and hence size of the grids, will be informed by the need to achieve adequate spatial coverage of each zone. In addition, power analysis can be used to try to ensure that the number of collected samples will allow for parity of detection differences between sites, both within and between regions. Within these grids, existing benthic data
Fig. 6. Line chart showing deviations (crosses) and the acceptable change limits in sediment composition for all four assemblage groups (lines). Lines and crosses are coloured according to the relevant cluster group (i.e. A - purple, B - orange, C - green, D - red). Individual deviations are numbered for the purpose of discussion in the text. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

should be assigned to the nearest grid node. Making use of historic sample data in this way will reduce costs for industry by reducing the number of new samples that need to be collected. In addition, the historic samples will provide data on an earlier condition of the sampled station. At nodes with no existing data, new data will be needed for macrofauna and sediments. Clearly this will involve an initial up-front cost to industry. However, costs will be similar to those of a typical pre-dredge benthic survey - which will no longer be required. Over the long-term, it is anticipated that industry will make considerable savings through not having to sample macrofauna within the P1/P2 areas.

5. Conclusion

Monitoring data from 2010 showed that the composition of sediments within the impact footprint of nine of the ten extraction areas in the East Channel Region remained within acceptable limits. This means that changes, should they persist, are unlikely to have major long-term ecological significance for dredging. For Area 473/2, where the level of percentage composition was below the minimum acceptable level, the changes were judged to not warrant further intervention given the demonstrated likelihood of natural recovery. The approach taken in this study offers a simple, objective and cost-effective means of assessing the acceptability of changes in sediment composition, and could simplify the existing monitoring regime.

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