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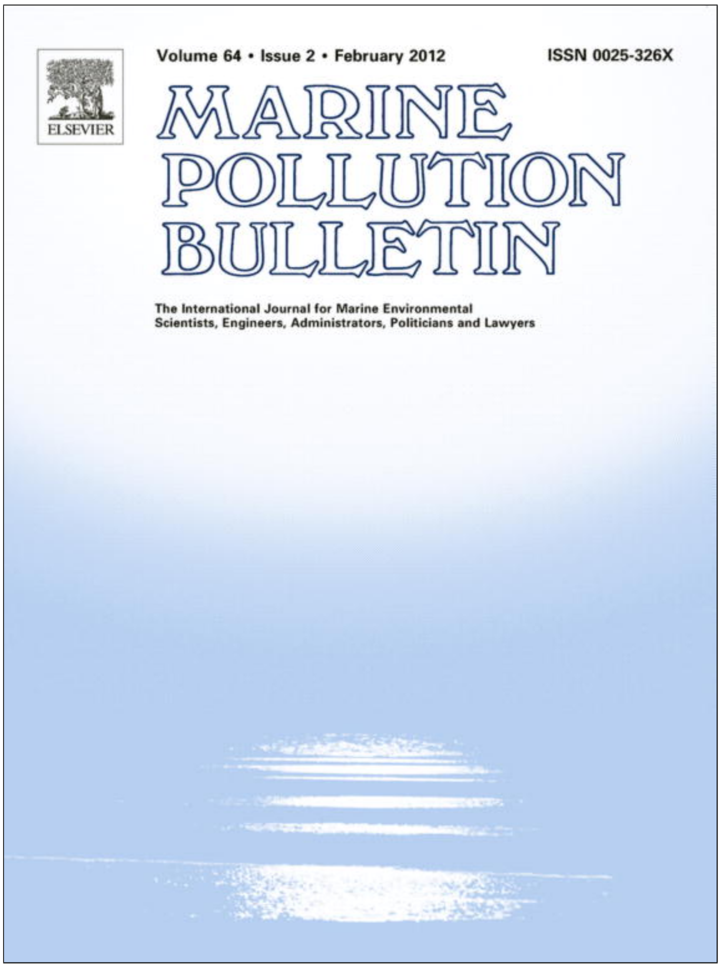

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Monitoring of East Channel dredge areas benthic fish population and its implications

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ABSTRACT

Regional annual sampling of commercial fish stocks formed a high priority for monitoring studies attendant with the granting of aggregate dredging licenses in the Eastern Channel Region (ECR) which had previously not been dredged.

An assessment of 4 m beam trawl sampling between 2005 and 2008 following the granting of licences in 2006 is provided. The majority of fish species have shown marked reductions in abundance since commencement of dredging. Draghead entrainment has been identified as a possible contributory cause based upon the known vulnerability of selected species (Drabble, 2012). Other environmental factors considered offer no explanation for the changes in abundance.

Comparative analyses with ICES data for plaice and sole over the study period demonstrate that changes in the ECR do not result from seasonal flux in the wider populations. An alternative impact model and potential mitigation measures are suggested.

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1. Introduction

Dredging for sand and gravel (marine aggregates) commenced in the Eastern Channel Region (ECR) of the UK in 2006 (Fig. 1). Deeper water reserves are being explored due to the depletion of established inshore and land based resources.

Ten licenses were applied for to exploit up to 8.5 million tonnes per annum (mtpa) over an area not exceeding 177 km^2 (Royal Haskoning, 2003). Extensive public consultation and public concern regarding potential cumulative effects prompted a five year monitoring programme, designed to measure change against baseline data. Annual sampling of fish stocks at 48 sites using a commercial 4 m beam trawl formed part of the programme.

While the direct and indirect ecological impacts of marine aggregate dredging on benthic macrofauna are well documented, less is known of the effects of trailer suction dredging upon benthic fish (Drabble, 2009; Carlin and Rogers, 2002). The sampling of commercial fish stocks to monitor the impacts of aggregate dredging was a new departure for the industry. Carlin and Rogers (2002) assess the theoretical sensitivities of fish resources to dredging but note that data on the distribution of the local biological resource is required to derive the vulnerability and scale of impact. Larson and Moehl (1990) compared fish entrained by dredgers with earlier trawl data from the mouth of the Columbia River, WA, USA. From the same estuary, trawl samples during dredging were compared against entrainment rates from a trailer suction dredger indicating avoidance of the dredger by some species (McGraw and Armstrong, 1990). The cumulative or in-combination impact of several dredge areas in a region on the structure of the benthic community is a topic largely unsupported by scientific research (Carlin and Rogers, 2002).

This review of the ECR 4 m beam trawl monitoring data for the period 2005–2008 sought to answer the following questions:

- Does the East Channel Association of Dredging Companies (ECA) sampling data suggest that aggregate dredging is having a significant effect upon the fish populations of the ECR?
- Do the observed changes provide new insight to the problem of benthic fish entrainment?
- By reference to wider ICES data, is it possible to attribute any observed changes within the ECR sampling data to broader variations in population change at an ICES area level?

The study follows research into potential fish entrainment rates for the ECR based upon a vulnerability index (Drabble, in 2012). The results are discussed in relation to current assumptions about dredging impacts on fish.

2. Methodology

Samples were taken using a 4 m beam trawl fitted with a 40 mm mesh codend deployed from a commercial trawler. The baseline characterisation of fish populations was principally derived from 4 m beam trawl surveys undertaken in June 2005 at 48 sites across the region. Six of these were reference sites considered to be outside the zone of both primary and secondary impacts of proposed aggregate dredging (Fig. 1). The author participated in the baseline survey.

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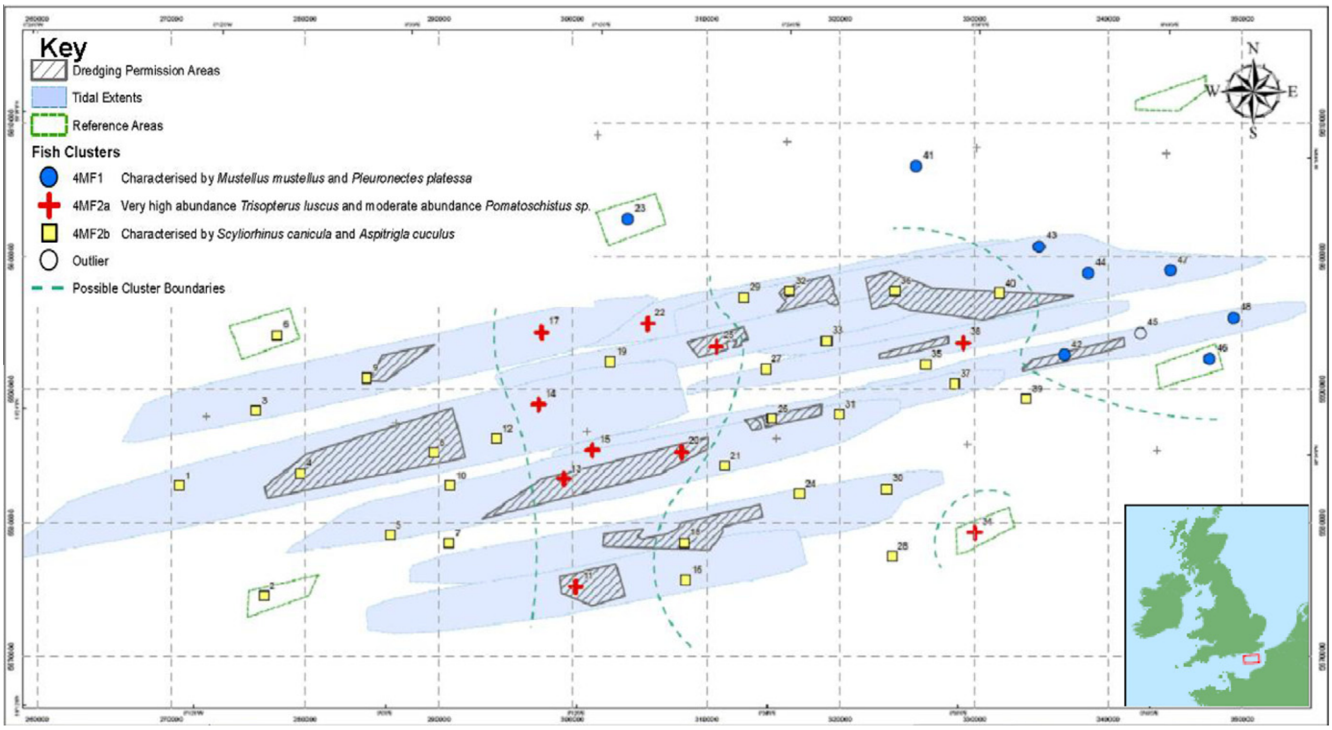

Fig. 1. Distribution of clusters derived from 4 m Beam Trawl, 2005 *Source:* East Channel Association and Emu Ltd., 2009a.

Upon recovery, fish species and commercially exploited shellfish were measured, and counted. For some species subsamples were weighted and counted to enable total populations to be estimated. Full details of sample processing that included epifaunal species are described in East Channel Association and Emu Ltd., 2008.

Baseline (June 2005) data was analysed together with three years of data for the period that dredging has been taking place (September of 2006, 2007 and 2008 surveys). Data analyses incorporated:

- A review of dredging activity data derived from Electronic Monitoring System (EMS) data;
- Multivariate analyses to investigate the null hypothesis that no difference existed between the 4 years of data (first for all 48 sites and then comparing impact zone and reference sites);
- A review of environmental data, specifically: fishing activity; sea temperature; time of survey and sampling regime;
- Age/length keys were applied to ECR plaice and sole, derived from ICES area VIId data, to compare any change in the population structure seen by the ICES survey with the ECR data;
- Recruitment indices were calculated for both the ECR and ICES Area VIId plaice and sole populations allowing direct comparison of year class recruitment indices.

3. Results

3.1. Dredging activity

No attempt has been made in this study to consider the distribution of dredging activity throughout the ECR. Rather, changes to the fish populations are considered in the context of the total area of dredging activity and comparison between impact zone and reference sites.

In 2008 the licensed area for dredging in the ECR had increased to 100 km^2. Fig. 2 shows the areas licensed, areas actively dredged and percentage of area impacted over the study period. A marked increase in the area impacted occurred between 2006 and 2007.

3.2. Multivariate analysis

Ordination of the fish data for the 4 years was undertaken using Bray Curtis % similarity index for faunal data clustering from the Plymouth Routine In Multivariate Ecological Research (PRIMER) suite (Clarke and Warwick, 2001; Clarke and Gorley, 2001).

Initial data transformation was applied using Square Root conversion to reduce skew in the data. Year codes were applied to the four data sets which were then analysed using ANOSIM to ascertain if there were any significant temporal annual changes, the null hypothesis for the global data set being "there is no difference between years". Analysis of the complete dataset indicated that there

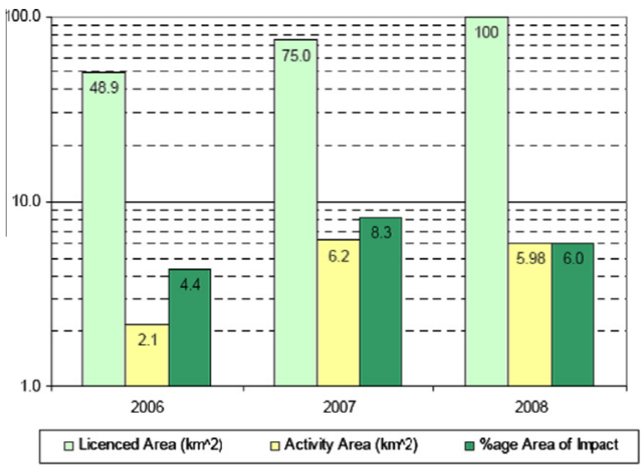

Fig. 2. Comparison of licensed area, activity area and percentage area of impact 2006–2008. *Source:* East Channel Association, 2009b.

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were differences in fish population composition between the sites but that these differences were relatively small across the year groups (Global $R = 0.278$, $p < 0.001$). However, these differences merit further investigation as they are within the range $0.5 > R \geqslant 0.25$ (Clarke and Gorley, 2001). Fig. 3 shows the MDS plot for the square root transformed data; the cluster for Year 1 (2005 pre dredging data) is generally separated from years 2 and 3 combined (2006–2007); year 4 (2008 data) appears more closely clustered to the pre-dredge data.

Pairwise comparisons tests between the different years are shown in Table 1, the probability of the pairwise tests being shown in brackets. The results in Table 1 indicate that there are significant differences between years ($p \leqslant 0.05$) but that R values show these to be comparatively small. The relative differences in the ANOSIM R values are highest between the baseline year, 2005, and subsequent years while dredging was in progress. There was negligible difference between 2006 and 2007 ($R = 0.072$ ($p < 0.001$)) notwithstanding a marked increase in the% area impacted (Fig. 2) but there is a higher relative difference in R between the 2006 assemblage and 2008 ($R = 0.294$ ($p < 0.001$)).

SIMPER analysis has been conducted to determine the principal species that account for 90% similarity at sites over the four year study period (Table 2). The blanks in Table 2 indicate where the species concerned did not contribute to the cumulative 90% abundance for the year listed. Two species, *Aspitrigla cuculus* (red gurnard) and *Callionymus lyra* (Dragonet) account for the greatest consistency in similarity between sites. Reductions in the abundance of *Scyliorhinus canicula* (Lesser spotted dogfish) and *Trisopterus luscus* (Bib) between 2005 and 2006 account for the changes in contribution to species similarity. These two species also account for the greatest dissimilarity between 2005 and 2006 and 2005 and 2008. *Microchirus variegatus* (thick-back sole) became increasingly abundant over the sampling period.

A null hypothesis of "no difference between baseline survey (2005) and dredging period surveys (2006–2008)" was tested using a 2-way crossed ANOSIM analysis for the 4 m beam trawl fish data only. The global ANOSIM across all year groups results in an R value of 0.374 ($p < 0.001$) demonstrating that slight differences exist in the total sample population across the year groups. The global result for testing differences between impact sites and the six reference sites for fish species averaged over four years, is 0.074 ($p < 0.129$) supporting the null hypothesis of no significant difference between the reference sites and 'impact zone' sites. Table 3 shows differences exist between the year groups most noticeably between 2005 and subsequent years but negligible difference exists between the six Reference sites and the 'impact zone' sites within the overall data comparisons.

Table 1
ANOSIM Pairwise test results for ECA data: 2005–2008.

	2005	2006	2007	2008
2005		0.383 ($p < 0.001$)	0.437 ($p < 0.001$)	0.301 ($p < 0.001$)
2006			0.072 ($p < 0.001$)	0.294 ($p < 0.001$)
2007				0.194 ($p < 0.001$)

Table 2
SIMPER Analysis result: Percentage contribution of species that account for 90% similarity between sites 2005–2008.

Species	2005	2006	2007	2008
Scyliorhinus canicula	34.06			6.14
Aspitrigla cuculus	28.2	48.65	45.08	43.87
Callionymus lyra	24.24	35.34	26.89	22.95
Trisopterus luscus	4.17			
Microchirus variegatus		2.83	7.22	10.42
Trigla lucerna		3.27	6.01	
Gobiidae spp.			3.9	3.77
Trigloporus lastoviza			3.43	
Microstomus kitt				2.88
Totals	90.67	90.09	92.53	90.03

The overall multivariate analysis shows a broadly similar fish assemblage with a small but significant element of change over time. This pattern was consistent for both the impact sites and reference sites. Further investigation was made of change in individual species abundance against known vulnerability to entrainment (Drabble, 2012).

3.3. Observed population changes among species considered vulnerable to entrainment: ECA trawl data 2005–2008

Fig. 4 shows the total abundance per 1000 m trawl for the species for which the mean value was equal to or greater than 0.1, broken down between reference and impacted sampling sites.

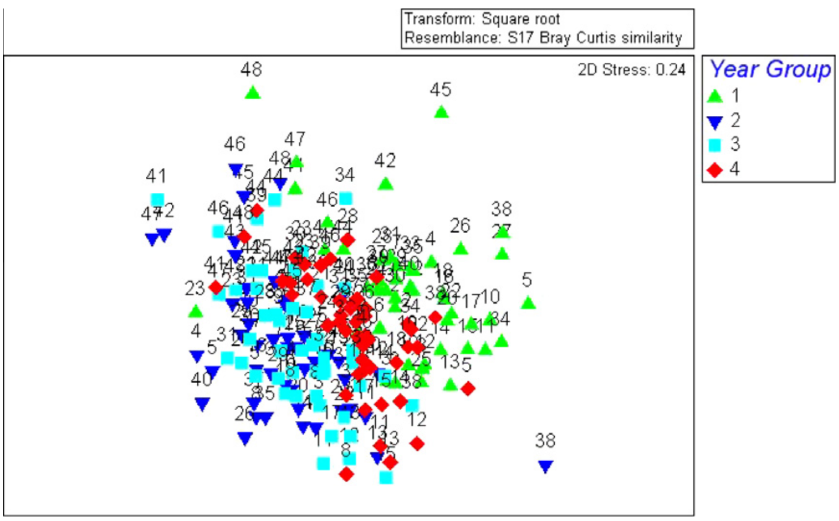

Fig. 3. Square Root Bray Curtis MDS plot.

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Table 3
Results from ANOSIM 2-way crossed analysis of impact zone sites and reference sites for ECA 4 m beam trawl data fish species: 2005–2008.

Years considered	Global R values between year groups across all Impact Groups	Global R values from test between Impact Groups
All years	0.287 ($p < 0.001$)	0.074 ($p < 0.129$)
2005–2006	0.411 ($p < 0.001$)	0.067 ($p < 0$ .231)
2005–2007	0.459 ($p < 0.001$)	0.114 ($p < 0.12$)
2005–2008	0.322 ($p < 0.001$)	0.102 ($p < 0.158$)
2006–2007	0.069 ($p < 0.003$)	0.046 ($p < 0.295$)
2006–2008	0.289 ($p < 0.001$)	0.033 (P < 0.356)
2007–2008	0.185 ($p < 0.001$)	0.08 ($p < 0.192$)

3.3.1. Plaice and sole

Marked reductions have occurred in the populations of both sole and plaice within the ECR. Increases above the 2006 low have occurred in 2007 and 2008 but abundances are 36% and 40%, respectively of 2005 sample populations. These percentage reductions are greater than any year on year changes in spawning stock biomass recorded from ICES data since 1980. Disturbance of the sea floor by dredging may, under certain conditions, enhance benthic productivity and result in increases in commercial yields (ICES, 1992). Increases in 2007 and 2008 may be accounted for by colonization of opportunistic species e.g. polychaetes that are preferred prey for some flatfish (Claveleau, 2009). Fig. 4 alone provides insufficient evidence to confirm that dredging since 2006 accounts for the reductions in plaice and sole from the pre-dredging 2005 population. However, changes in population structure evident from age-length analysis show an interruption to recruitment.

3.3.2. Elasmobranchs

All elasmobranch species show a downward trend in numbers (Fig. 4). Comparison with species populations from ICES data, not yet undertaken, would differentiate dredging impacts from natural variations in stock levels. However, vulnerability data suggests that reductions in the local population of both *Raja clavata* and *Scyliorhinus canicula* (Fig. 4) may in part reflect entrainment (Drabble, 2012). 4 m beam trawl gear can under-represent large batoids (ICES, 2008), however, a clear downward trend in *Raja clavata* has occurred. Elasmobranchs have been classified as marine stragglers, i.e. species that spawn at sea and typically enter estuaries only in low numbers and occur most frequently in the lower reaches (Henderson and Bird, 2009); they are, therefore, less likely to feature in earlier entrainment studies that have focussed on estuarine environments (Drabble, 2012). Further investigation would be needed to ascertain whether entrainment or other factors account for the apparent decline in Smooth hound.

3.3.3. Scorpaeniformes including Triglidae

Collectively, there is no consistent pattern of population change for the Scorpaeniformes (Fig. 4). Only Tub gurnard has shown a marked reduction in population. Scorpaeniformes, particularly

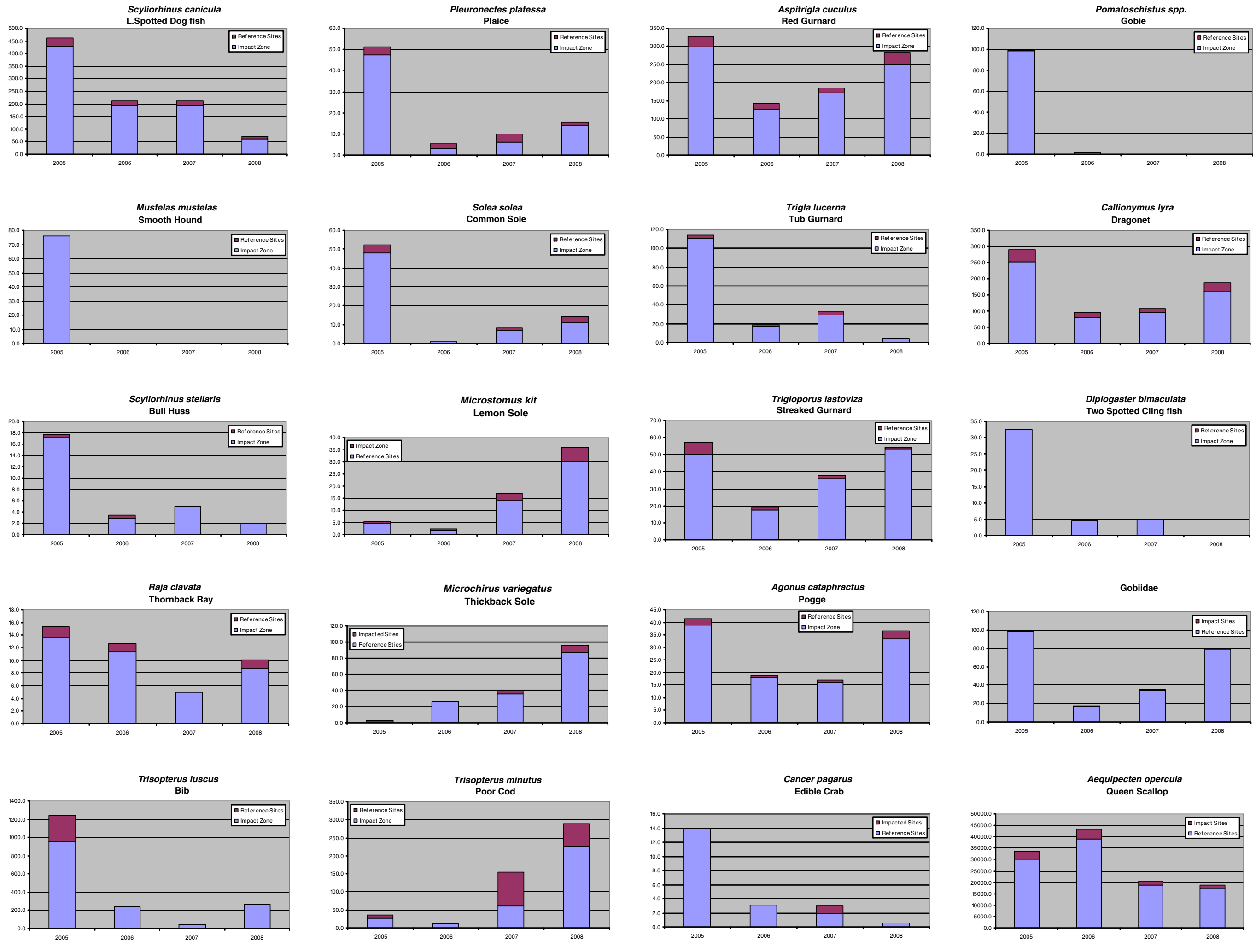

Fig. 4. Abundance data for common ECR species, 2005–2008 differentiating between reference (maroon) and main sampling sites.

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Triglidae are vulnerable to entrainment (Drabble, 2012). While entrainment may be occurring, the populations of red gurnard, streaked gurnard and pogge show no link to dredging activity. Tub gurnard enjoyed relatively high abundance across the central eastern areas of the ECA in 2005; the population moved to the western half of the ECA in 2006 and 2007 but with numbers reducing each year. Abundance per 1000 m trawl in 2008 was 5 compared with 114 in 2005. The influence of dredging activity at Areas 473E, 474 central and 458 upon Tub gurnard cannot be discounted.

3.3.4. Pomatoschistus spp.

Pomatoschistus pictus is prone to a high entrainment rate of 0.009/m^3 (Drabble, 2012). The vulnerability of this species to dredging is reflected in the population reduction for *Pomatoschistus* spp. (Fig. 4). Prior to dredging commencing the data shows fairly widespread distribution, particularly across the central portion of the ECA. Following commencement of dredging, only three individuals were recovered in 2006 and none thereafter. *P. pictus*, is known to inhabit gravel and shell-gravel habitats typical of those being targeted for extraction. Interestingly, other *Gobiidae* spp. showed reduced numbers in 2005 but significant increases in 2007 and 2008.

3.3.5. Two spot clingfish Diplecogaster bimaculata

Fig. 4 shows reductions in numbers of *D. bimaculata* sampled in 2006 and 2007 (from that of 2005) and no presence recorded in 2008. The species is prone to entrainment (Drabble, 2012) and the data suggests that dredging could be having an impact upon this species.

3.3.6. Dragonet C. lyra

Fig. 4 shows no clear pattern throughout the period. While entrainment is likely to be occurring (Drabble, 2012) any effects upon the regional population are unclear at this stage.

3.3.7. Other species

A range of other larger epifaunal species are entrained by dredging including crabs, squat lobsters, bivalves – notably scallops and echinoderm species that are important in providing prey to benthic fish populations. Removal of these organisms can potentially significantly influence the population dynamics amongst different fish species throughout the area.

4. Review of other environmental data

Year to year variability in species' populations occurs in response to a range of environmental stimuli particularly the physical and biological processes that affect recruitment (Jennings et al., 2000). The potential influence of fishing effort, sea temperature and timing/conduct of surveys have been considered in relation to the ECR data but there is no evidence to suggest that any of these factors were responsible for the changes observed in fish species abundance.

5. Analyses of age structure of sampled species both within the ECR and the wider ICES Area VIID populations

The ECR data showed no significant difference between impact zone sites and reference sites. By comparing the ECR data with ICES Annual 4 m beam trawl sampling data an assessment was made of whether the ECR changes were reflected in broader population changes deemed unrelated to dredging.

To differentiate dredging-related impacts from natural variations in abundance, changes in the age structure of the ECR sole and plaice have been considered alongside profiles for stock levels from ICES annual 4 m beam trawl sampling data.

The relative mean abundances of sole and plaice year-classes caught at ages 2-4 in each survey were calculated for both the ECR population and for the ICES area VIId population adapting the method used by Pickett et al., 2002 (after Pawson, 1992). Age groups 2–4 were selected to provide consistent sampling data for these age groups. The fish were not aged during sampling and so age-length keys based upon the respective year groups for the ICES data were applied to the ECR population. The ECR abundances were doubled to standardize for a 30 min trawl. The year–class relative abundance index or recruitment index for sole and plaice, based on all surveys on each year–class, was calculated for both the ECR and the ICES data populations enabling a direct comparison to be made (Figs. 5 and 6).

The zero values for the ECR age 2 and age 3 year groups in 2001 and 2002 are void and should be disregarded. Year class abundance is coincident for both the ECA and ICES data 2003 and 2004. While recruitment is generally lower for the ECA populations for both sole and plaice, there is some correspondence between the fluctuations in recruitment between the ECA and ICES data, particularly for sole (Fig. 5) where the curves tend to follow a similar pattern.

This analysis (Figs. 5 and 6) allows the ECR data to be set in the context of longer ICES time series data. The recruitment index is calculated from the annual strength of the three year classes; consequently, the effects of dredging will not begin to feature in the analyses until 2008 when the first age 2 classes from 2006 are included in the calculations. A further 2 years lead time is required before the age 4 class from 2006 features, i.e. the population under

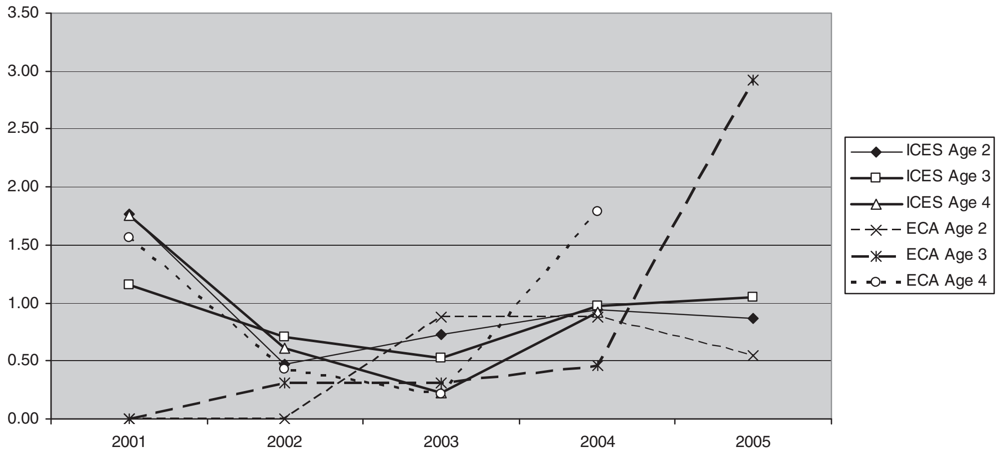

Fig. 5. Recruitment indices for sole–ECA population against ICES area VIId population: 2001–2006.

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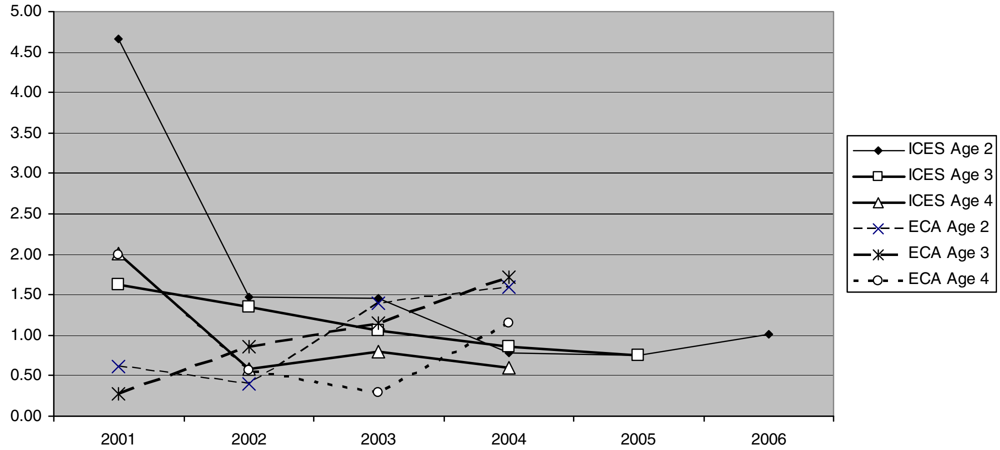

Fig. 6. Recruitment indices for plaice–ECR population against ICES area VIId population: 2001–2006.

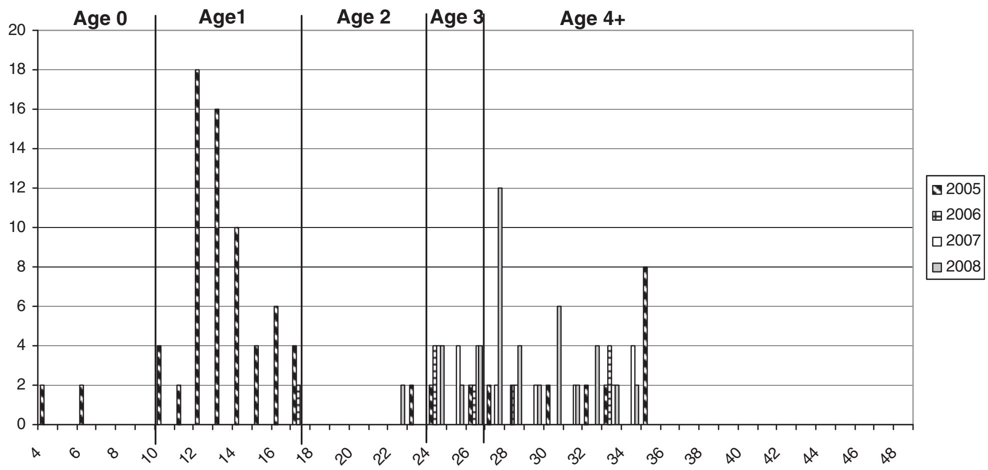

Fig. 7. Changes in length distributions and age for sole in the ECA over the period 2006–2008.

consideration is drawn entirely from a dredging-influenced environment.

It is possible to predict with a degree of confidence the likely effects upon recruitment based upon changes in age group strength by species of the ECA population, to date. Fig. 7 shows the age length distributions of sole from the 4 years of sample data for the ECR. The age-length key has been calculated from the 2008 ICES data for area VIId. The 2005 data shows an abundance of age 1 sole, relatively high numbers of age 4 sole but low counts for ages 3 and 2. Low numbers for age 0 fish may be attributable to the unsuitability of the 4 m beam trawl for sampling this size fish and / or the lower abundance for this age group in the central areas of the English Channel. This pattern correlates very closely to the recruitment data for sole for ICES area VIId (Fig. 9). Age 1 recruitment was high in 2005 but year groups 2 and 3 were low; age 4 fish form part of the 2001 class which was the strongest year class since 1990, the second strongest being 2004 (Cefas, 2009).

One might expect the 2006 age length distribution in Fig. 7 to reflect the 2005 distribution with ages 2 and 4+ being strong and a relatively healthy age 1 recruitment suggested by Fig. 8. In contrast to expectations, no age 2 fish were sampled in 2006. In 2007, the age three group to some extent reflects the strong 2004 year class. The 2008 distribution is dominated by the age 4+ older fish that pre-date the commencement of dredging together with evidence of the relatively strong 2005 year class. The population age structure differs markedly from the ICES data that shows healthy age 1 and 2 groups for 2006 (Fig. 9).

Fig. 8. Age 1 recruitment for sole in the Eastern English Channel (ICES Division VIId). Cefas, 2009

The data suggests that there has been a reduction in the ECR sole population, post 2005, which cannot be explained solely by natural variation.

A similar pattern exists for plaice (Fig. 10). The age 0 population in 2005 should feature prominently in the age 1 population in 2006 and age 2 population in 2007. Sampling data indicates that there is no evidence of age 1 fish in the 2006 population, and low abundance of age 2 fish in the 2007 population. These data indicate a disturbance to the overall population. It will also be noted from Fig. 10 that the increase in abundance for plaice shown earlier in Fig. 4 comprises fish aged four years or more from the 2004 year

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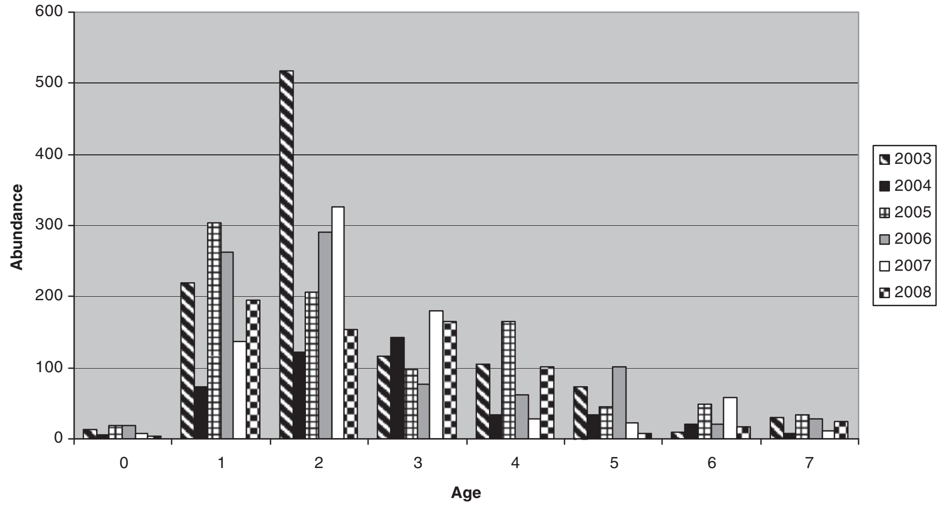

Fig. 9. Abundance by year and age of sole for ICES Area VIId.

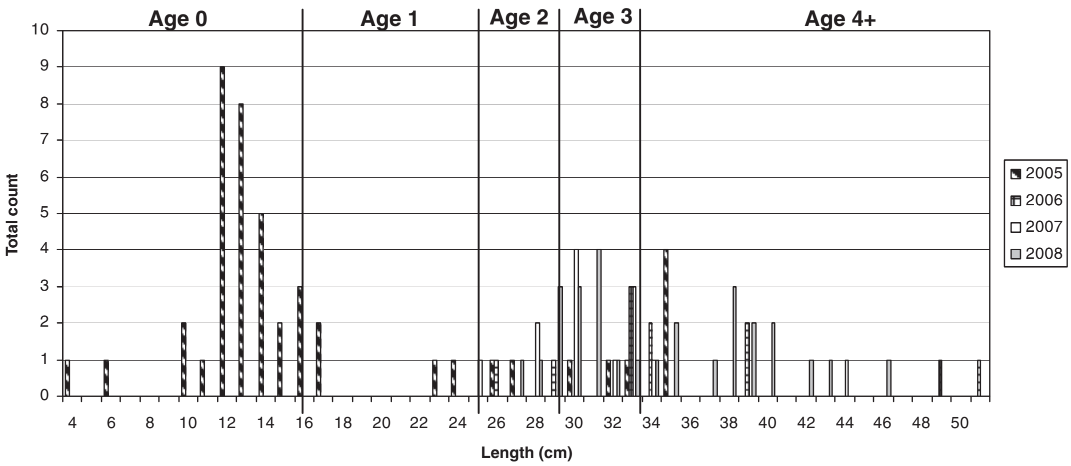

Fig. 10. Changes in length distributions and age for plaice in the ECA over the period 2006-2008.

class or earlier. Recruitment for plaice has been poor in comparison with historical levels. Lower abundances for plaice in the ECA figures since 2005 will, in part, account for the absence of younger fish. Historical tagging information suggests that 40% of the juvenile plaice in Division VIId come from nursery grounds in the North Sea (ICES, 2009). However, the most recent data indicates that recruitment in 2006 and 2007 has been above average (ICES, 2009). In contrast with the ECR data, the ICES area VIId data shows age 1 recruitment for 2006, 2007 and 2008 to be significantly higher than 2005. The year 0 recruitment for 2006 is also markedly higher than the year 0 for 2005. As with sole, the data suggests that there has been a reduction in the ECR plaice population, post 2005, which cannot be explained solely by natural variation.

Both the relative mean abundance values for different age groups and the annual recruitment indices for different year groups relate to the pre-dredging era for sole and plaice. Figs. 7 and 10, suggest that the weakness of the 2004 year groups for sole and plaice since 2006 will impact heavily upon recruitment. It is predicted that successively, the age 2, 3 and 4 recruitment indices for both plaice and sole will fall away from the equivalent ICES population values over the period from 2010 onwards as both the existing and future populations reflect the changes that have occurred.

Reference to similar populations in the wider area has also been endorsed by the technical working group responsible for monitoring the impacts of aggregate dredging in the ECA as a means of establishing and refining impact thresholds (East Channel Association and Emu Ltd., 2005).

6. Discussion

6.1. The discussion first revisits the questions underlying the study in the light of the data analyses

Does the ECA sampling data suggest that dredging and specifically entrainment through the draghead is having an effect on species populations?

Testing of the null hypothesis, "there is no difference between years" by ANOSIM indicates that the similarities across year groups are greater than the differences (Global $R = 0.278$, $p < 0.001$). The value of Global R indicates that there is a difference component in the data and the pairwise analyses of year groups shows the relative differences in R to be greatest between 2005 and the 3 years following commencement of dredging (0.383, 0.437 and 0.301, respectively ($p < 0.001$). Sample populations have reduced for a range of species since 2005; some ECR species populations have

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increased in size over the sampling period, notably, *Trisopterus minutus* (poor cod), *M. variegatus* (thickback sole) and *Microstomus kitt* (lemon sole). From entrainment monitoring data (Reine and Clarke, 1998) and ECR sampling data, the vulnerability of species to entrainment has been estimated (Drabble, 2012). Reductions in a number of the species sampled include those vulnerable to entrainment, specifically elasmobranchs, *D. bimaculata* (two spotted clingfish) *Pomatoschistus* spp. *Pleuronectes platessa* (plaice) and *Solea solea* (sole). For the latter two species, the absence of year 0 recruitment following commencement of dredging and near absence of year 1 fish suggests entrainment may be impacting these species. A range of other anthropogenic or natural factors were investigated to identify possible links to these localised changes but no clear underlying causes emerged.

The predicted effect of dredging within the ECR reference sampling sites was "no anticipated loss of fauna due to any activity related to dredging" (East Channel Association and Emu Ltd., 2005). Further investigation to test the null hypothesis of "no significant difference between the reference sites and 'impact zone' sites" using the 2 way crossed ANOSIM showed negligible difference $R = 0.074$ ($p < 0.129$) suggesting the reference sites are experiencing the same pressures as the 'impact zone' sites.

At the edge of the licence area, when turning, it is normal practice for dredger crew to lift the draghead 1.5–2 m off the seabed, a height at which no gravel enters the pipe with the pumps still running. Entrainment of fish occurs unimpeded when the draghead is being trailed in this manner resulting in a 'footprint' that can extend well beyond the licence area. The reference sites, located between 4 and 15 km of the licence areas may not therefore be appropriately positioned to monitor un-impacted change for benthic fish communities.

The absence of statistical difference between ECR impact and reference sites can and has been used to discount dredging as a cause for changes in abundance (The East Channel Association, 2011). Investigation of wider reference data from ICES annual sampling is valuable as a means of demonstrating whether the ECR changes are reflected in natural flux affecting wider species populations and indeed validating the original monitoring strategy.

6.2. Is it possible to attribute the observed changes within the ECR sampling to broader variations in population change at an ICES area level?

From comparative analysis of sample populations for plaice and sole in both the ECR and the wider ICES area VIId data it is evident that, for these indicator species, the population reductions and poor recruitment observed from 2006 to 2008 in the ECR are not reflected in the wider species populations. The clear differentiation between the ECR and ICES sample populations weakens the argument that the changes in the former result from natural flux and calls into question the validity in selection of the reference sites. Given the clear source–pathway–receptor evidence for entrainment of sole and plaice, population reductions are considered, at least in part, to result from entrainment.

The ECA blueprint undertook to establish and refine thresholds for management intervention based upon "year to year differences and differences outside of those occurring within similar populations found at the reference sites and in the wider area". To date, the data reported here represents the only comparison with the ICES data and it raises important questions about both the causes of population changes and the management response as the quinquennial review of dredging monitoring data for the ECR is undertaken.

Comparative analysis of recruitment indices of an impacted and wider reference population, as illustrated by Figs. 5–10, offers the following benefits:

- Direct comparison of species from two independently sampled populations;
- It discourages the tendency to confuse site variability within a discrete data set with annual variability;
- Age profiling of the potentially affected population against wider data sets allows a 'telescopic' view of the data; for example, taking an age four population, one can compare the strength of year class over four previous years, rather than reliance upon one baseline year of data; and
- Any changes to the impacted population can be identified earlier and with greater confidence because of the extended temporal and spatial frame of reference.

6.3. Impact model for aggregate dredging

The evaluation of ecological impacts and the potential for recovery focussed for a number of years upon infauna although additional consideration of epifauna now features in most literature. The monitoring blueprint for the ECA identifies four zones; an Active Dredge Zone (ADZ), a Primary Impact Zone (PIZ) a Secondary Impact Zone (SIZ) and a No Impact Zone that is everywhere outside of the PIZ and SIZ, together with anticipated effects (Table 4).

Fish entrainment is not identified as an anticipated effect in Table 4, notwithstanding the body of published scientific evidence of the effects of fish entrainment from hydraulic dredging, examples of which have been summarised in Drabble (2012). One of the reasons offered is that relatively little is published

Table 4
Anticipated effects of Dredging Activity Emu Ltd. (2005).

Title and character of activity	Anticipated effect
Active Dredge Zone (ADZ) – in the process of being dredged at the time or immediately preceding the survey period. This is a subset of the Primary Impact Zone (PIZ) as it will not be static over time, but will always remain within the PIZ	Complete or almost complete loss of fauna, both epifauna and infauna in the immediate vicinity of the dredging activity. Defined as highly significant detectable differences from baseline and reference areas
Primary Impact Zone (PIZ) – comprising the area that may be actively dredged during the lifetime of the licence and hence subject to relatively severe direct impacts at times	Partial lost of both epifauna and infauna due to direct and indirect effects. Partial recovery may occur in this area due to the cessation of dredging in part of the zone, however, continued effects may be felt from indirect sediment deposition and seabed sediment mobilisation. Defined as significant detectable differences from baseline and reference areas
Secondary Impact Zone (SIZ) – This area falls outside of the area that will be actively dredged, although it may be subject to peripheral and indirect impacts	Partial loss of fauna, primarily the epifauna, due to deposition and or mobilisation of the seabed sediments. Impacts will be on a gradient from the immediate boundary of the PIZ to the outer edge of the SIZ at which point no impacts are anticipated. Defined as marginal detectable differences from baseline and reference areas
No impact and reference areas. No anticipated loss of fauna due to any activity related to dredging	No detectable difference from baseline

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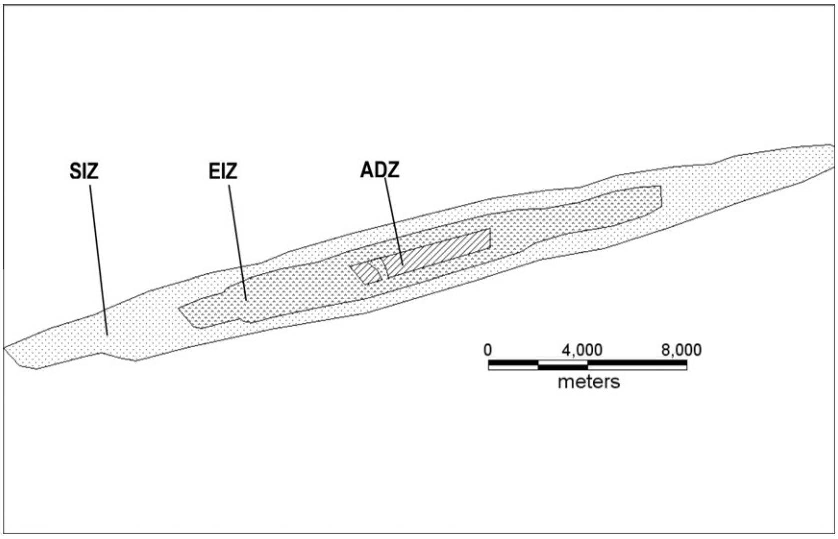

Fig. 11. Revised Conceptual Model for Assessment of Dredging Impacts.

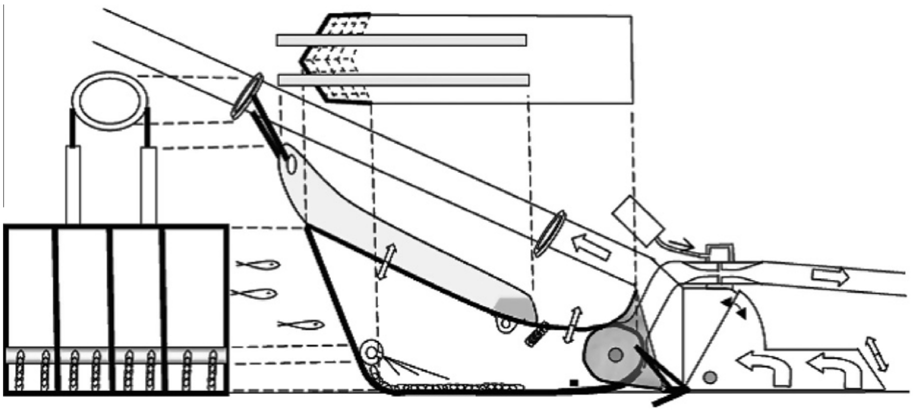

Fig. 12. Representation of Faunal Friendly Dredging System (FFDS) Showing front and plan sections.

concerning the impacts of dredging on fish and fisheries although direct mortality is acknowledged for fish unable to avoid the dredger (Cefas, 2002). Evidence of vulnerability (Drabble, 2012) combined with the absence of statistically significant differences between the reference areas and the impacted areas within the ECR suggests that the ECA impact model is unsuitable for assessing the full impacts upon benthic ecology.

Recognising that entrainment affects all trophic levels in the benthic environment, a revised generic model for assessing dredging impacts is proposed. For infauna and sessile epifauna, the PIZ and SIZ remain unchanged. A new Entrainment Impact Zone (EIZ) is introduced that encompasses all mobile organisms, nekton and plankton that exist in the benthic water layer and move with the current. This approximates the tidal excursion close to the seabed and is illustrated by Fig. 11. The SIZ shows the tidal excursion at the surface based upon the closest available Admiralty tidal diamond. The EIZ has been calculated by applying the one seventh power law calculated at 34 m of an average 35 m of water column. This equates to approximately half the tidal velocity at the surface. The EIZ is calculated from the ADZ coordinates and, if dredging is restricted to a zone within the dredge licence area, would reduce commensurately.

The EIZ is a zone of potential impact; not all fish, plankton and larvae in this zone will be entrained. However, all biota occupying this zone for any length of time will, at some point, be likely to come within the flow field of a draghead; plankton will be entrained together with a range of the nekton. Quantifying this risk is achievable with the aid of numerical hydrodynamic models, scenarios for dredging intensity and field sampling of benthic fish, mobile epifauna and plankton. Such methods are extensively used in the assessment of entrainment for cooling water intakes using the PISCES (Prediction of Inshore Saline Communities Expert System) software. Similar analyses may aid a better understanding of the apparent reductions and poor recruitment in the fish populations within the ECR.

6.4. Reducing the impacts of entrainment from dredging

Approaches and equipment development to address dredging impacts has focused on reducing turbidity associated with overflow from hopper dredges. Little development has occurred in either equipment or dredging approaches devoted to the key issue of loss of benthic communities that forms the focus of this study and is acknowledged as the most important impact (Baird et al., 2004). In the UK, environmental windows have been introduced in response to specific issues, notably restrictions on dredging at selected sites where and when herring spawning is known to take place (ECA and MarineSpace, 2008) and restriction on dredging at Hastings Shingle Bank during the known inshore migration of Dover sole (Emu Ltd., 2007; Rogers and Nicholson, 2002). Research in

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mainland Europe is investigating the use of water jets to deflect fish from the path of dragheads that may offer one of the more promising paths toward mitigation. Environmental windows, while currently necessary to avoid sensitive life cycle phases, create considerable difficulties for the marine aggregates industry interrupting continuity of supply to markets and adding to costs.

Ecological impacts with marine aggregate extraction occur because the draghead does not distinguish between the targeted resource and the organic material in its path. The organic content of aggregate is unwanted and, when proportionally high, incurs additional expense through intensive washing or disposal. Increasingly, the ecological implications of entrainment limits where and when extraction is permitted, adding costly delays to the granting of licences and onerous monitoring regimes. Product innovation is therefore required to better control and mitigate the effects of dredging (van Muijen 2008; Baird et al., 2004).

The Faunal Friendly Dredging System (FFDS) is a conceptual design to reduce the direct impact of the draghead upon the mobile epifauna, fish and plankton by removing a proportion of the fauna in advance of the main suction (Drabble, 2009). Dragheads already entrain mobile organisms as an unintended by-catch but with the FFDS a significant proportion of marine life will be captured in a forward funnelled chamber. A combination of hydrodynamic flow (as the dredger progresses through the water) augmented by low grade suction channels these organisms via a bypass duct, returning them to the seabed largely unharmed and without compromise to the dredging process (Fig. 12). The concept incorporates design principles and technologies that are widely used and proven in the fishing and dredging industries.

7. Conclusions

Analysis of ECA sampling data over the period 2005–2008 provides evidence that certain species, identified as vulnerable to entrainment, have undergone marked population reductions over the period, notably, Bib, *T. luscus*, Dogfish, *Scyliorhinus* spp., Tub gurnard, *Trigula lucerna*, Sole, *S. solea*, Painted goby, *Pomatoschistus* spp. and Two spotted clingfish *D. bimaculata.* Conversely, marked increases occurred with certain species, including Thickback sole, *M. variegatus,* and Lemon sole, *M. kitt*, species that evidence may suggest are vulnerable to entrainment (Drabble, 2012). Further age-length analysis for plaice and sole and comparison of year class recruitment indices with the ICES 4 m beam trawl data provides clear evidence of disturbance to the ECR population following the onset of dredging that cannot be explained by natural variations in population.

A revised model for assessment of dredging impacts has been proposed incorporating an Entrainment Impact Zone (EIZ) that approximates the tidal excursion at the benthos. Entrainment risk to both plankton and sensitive nekton can be modelled within the EIZ using hydrodynamic modelling.

Approaches to mitigating the impacts of entrainment to fish/mobile epibenthic species have been discussed and the concept of a Faunal Friendly Dredging System introduced offering a potential path to mitigating these effects.

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