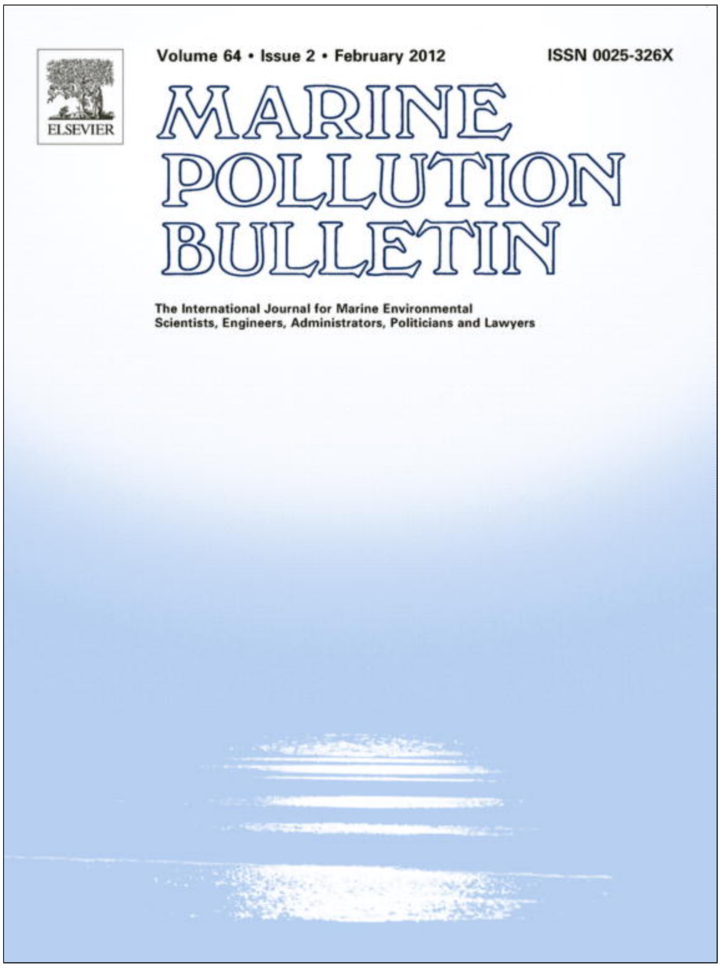
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Projected entrainment of fish resulting from aggregate dredging

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ABSTRACT

Previous research to assess impacts from aggregate dredging has focussed on infaunal species with few studies made of fish entrainment. Entrainment evidence from hydraulic dredging studies is reviewed to develop a sensitivity index for benthic fish. Environmental monitoring attendant with the granting of new licences in the Eastern Channel Region (ECR) in 2006 offers a unique opportunity to assess the effects of dredging upon fish. Projected theoretical fish entrainment rates are calculated based upon: abundance data from 4m beam trawl sampling of fish species over the period 2005–2008; sensitivity data; and dredging activity and footprint derived from Electronic monitoring System (EMS) data. Results have been compared with actual entrainment rates and also against summary results from independent analysis of the changes in fish population over the period 2005–2008 (Drabble, 2012). The case is made for entrainment surveys to form part of impact monitoring for marine aggregate dredging.

1. Introduction

Marine aggregates are of strategic and increasing importance to the UK construction industry (Highley et al., 2007). Both marine aggregate extraction and navigation dredging have a wide range of potential impacts on the marine environment (Carlin and Rogers, 2002). These can be broadly categorised as primary impacts from entrainment (the direct uptake of aquatic organisms by the suction field generated at the draghead), and secondary impacts associated with the dredge plume generated by the discharge of suspended sediment (Newell et al., 1998). This paper focuses on marine aggregate dredging undertaken by trailer suction hopper dredgers. While navigation dredging involves similar processes, the nature of the impact upon seabed ecology can be quite different because of differences both in the relative intensities of dredging undertaken and the nature of the benthic communities affected.

Population scale impacts to fish through entrainment have previously been assessed as low in view of the mobility and lower abundance of fish and commercially important shellfish relative to other benthic invertebrate species (Carlin and Rogers, 2002).

Dredging for sand and gravel (marine aggregates) commenced in the Eastern Channel Region (ECR) of the UK in 2006 (Fig. 1). Monitoring of the ECR provides a unique time series of benthic fish population data and aggregate dredging intensity data to consider potential entrainment impacts.

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2. Materials and methods

The objectives of the study were to:

(a) Review literature on dredging impacts to characterise the sensitivity of different habitats and fish species to entrainment by dredging;
(b) Describe the baseline environment in terms of habitats and species; and
(c) Estimate potential entrainment rates for selected benthic fish species based upon:
- Known sensitivities of fish species to entrainment;
- Annual sampling data (from which distribution has been estimated);
- Typical dredging production rate and footprint; and
- Electronic monitoring System (EMS) data.

(d) Validate the projected entrainment rates against published entrainment rates from earlier dredging impact studies.

3. Review of fish entrainment literature

Maintenance dredging and marine aggregates dredging can be expected to result in a 30–70% reduction of infaunal species diversity, a 40–95% reduction in the number of individuals, and a similar reduction in the biomass of benthic communities in the dredged area (Newell et al., 1998). A gradient of impact has been suggested from low impact in dynamic areas of high natural stress such as shallow mobile sands to more stable deepwater gravel environments e.g. central English Channel (Emu Ltd., 2004).

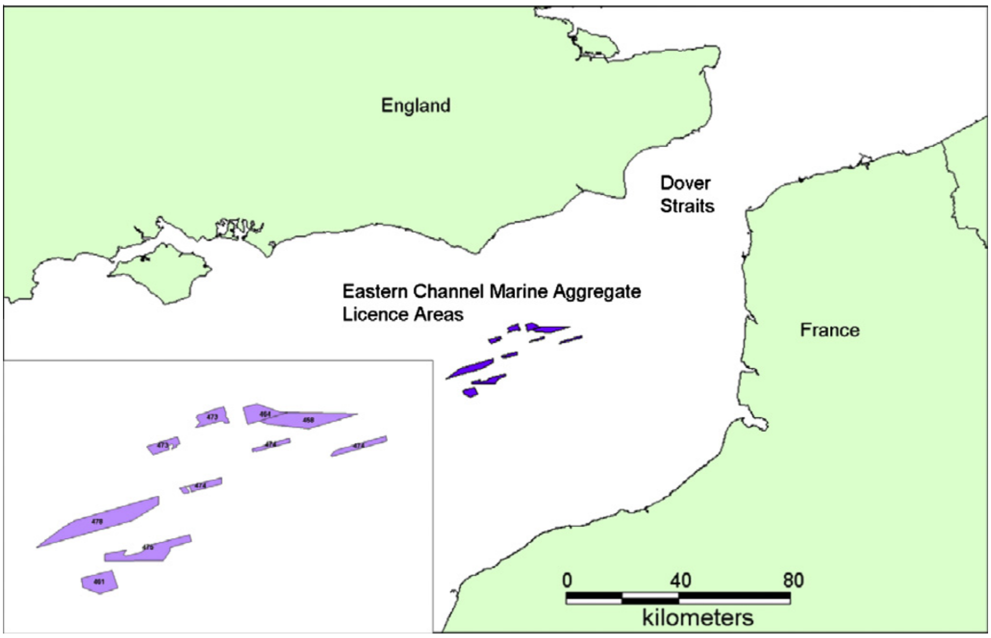

Fig. 1. Eastern English Channel licence areas.

No comprehensive studies have been undertaken of fish entrainment associated with aggregate dredging, however, Reine and Clarke, 1998 undertook a comprehensive review of entrainment studies associated with navigation dredging. While the subject of their review was navigation dredging, similar types of vessel and equipment were included to those used in marine aggregate dredging, albeit population scale impacts differ because of differences in the footprint and intensity of the two types of dredging. Areas that are subject to frequent maintenance dredging tend to fall into the category of mobile sands hosting opportunistic species that are adapted to both natural and anthropogenic disturbance. Furthermore, the direct footprint of the draghead is restricted to a narrow navigational channel.

Larson and Moehl (1990) measured entrainment between 1986 and 1989, using a specially designed sampler that intercepted material before it entered the hopper. The sampler could handle the discharge of one discharge pipe for 30–60 s. A total of 789 samples were taken and the majority of species entrained were demersal. Relatively few pelagic species were collected, mostly anchovy, herring and smelt. Highest entrainment rates were for the Pacific sanddab (*Citharichthys sordidus*), Pacific staghorn sculpin (*Leptocottus armatus*), and the Pacific sand lance (*Ammodytes hexapterus*) at 0.099, 0.120 and 0.777 fish/m^3 respectively, with sand lance accounting for 92% individuals entrained in one study (Larson and Moehl, 1990). Of 28 species of fish identified from entrainment samples, 24 occurred in the outer harbour samples and eight from the inner harbour (McGraw and Armstrong, 1990).

Simultaneous trawls formed part of one study to characterise fish populations at times of dredging and allow comparisons that may inform the sensitivity of different species to entrainment (Armstrong et al., 1982 after McGraw and Armstrong, 1990). Comparison of trawl data and entrainment data indicated that larger crabs and some fish were avoiding the dredge. However, the species conspicuous as absent from the entrainment data, buffalo sculpin (*Enophrys bison*), starry flounder (*Platichthys stellatus*) and shiner perch (*Eumotogaster aggregata*) were species that were not ubiquitous to the area of seabed being dredged (McGraw and Armstrong, 1990). Trawl comparison data showed trawl catch rates were several times higher than were entrained by the dredge. The exception was Pacific sand lance, where the apparent contradiction was explained by the fast swimming ability of the sand lance, allowing them to escape a trawl when first touched by a tickler chain and their burrowing behavior making them vulnerable to entrainment by powerful suction dredgers (McGraw and Armstrong, 1990).

In 1992 an initial study was conducted on the physical condition of benthic organisms discharged to sea along with the outwash from a trailer suction aggregate dredger operating in previously unworked areas. In total 23 fish were encountered, all but one from intercepting the hopper spillways. Most fish appeared physically undamaged and, evidently, a large proportion would have been washed back to sea. The fish caught in the spillway were five two spotted clingfish, *Diplecogaster bimaculata*, in two of which the flesh was torn, four undamaged dragonets, *Callionymus lyra*, and 13 painted gobies, *Pomatoschistus pictus*, of which one showed signs of severe damage and three had been dissected. From the hopper, one red gurnard, *Aspitrigla cuculus*, was retrieved (Lees et al., 1992).

Noting that anecdotal records of observations by fishermen and marine biologists can form a useful, qualitative description (Carlin and Rogers, 2002) dredger crew members have confirmed that sole are entrained by dredgers – occasionally in large numbers. Aggregate wharfs on the continent at one point routinely used men to hook out fish from the conveyors as it was landed to the wharf (Paul Joy, Hastings Fisheries Protection Society personal communication, Feb 2010). Anecdotal evidence reported large numbers of fry, several crates of scallops and a large turbot present in dredge landings immediately following the Beach Recharge at Hastings, UK (Fred White, fisherman, Hastings 17 March 2010 personal communication).

The lack of a rigorous assessment of entrainment of fish/shellfish associated with aggregate dredging in the UK inhibits a clear assessment of the scale of impact on the wider species' populations and, therefore, whether or not mitigation is appropriate.

4. The study area: baseline description of the Eastern English Channel Region (ECR)

Dredging within the ECR represented a new departure for the management of marine aggregate extraction for a number of reasons, including:

- The area had, hitherto, not been dredged and, therefore, offered a unique opportunity to monitor aggregate dredging impacts from the outset;
- The scale of extraction envisaged (the ECR is estimated to hold 27 million tonnes of sand/reserves sufficient to meet demand for ten years or more);
- The nature of the seabed environment – aggregate dredging had never been undertaken in the ECR or any area with similar water depths and hydrodynamics (Royal Haskoning, 2003). The dredge areas are in deep water mostly in excess of 30 m. Theoretical dredging impacts to benthos in deep water (>30 m) complex stable gravel suggests that the presence of higher numbers of longer-lived and slower-growing species is likely to significantly extend the recovery time compared to shallower sites (Emu Ltd., 2004; Newell et al., 1998); and
- The scale of monitoring – there was recognition of the benefits of both a regional monitoring programme and regional assessment of the impacts of aggregate dredging (Royal Haskoning, 2003). The industry initiated regional monitoring plan that commenced in 2005 enables the potential cumulative effects of extraction from different licence areas within the region to be observed over time.

The baseline description of fish communities and epifauna was principally derived from 4 m beam trawl surveys undertaken in June 2005 at 48 sites across the region (Fig. 2). Six of these were reference sites that were considered to be outside the zone of both primary and secondary impacts of aggregate dredging. The procedures and study methods for characterising and monitoring the ecology of the ECR are set out in the East Channel Association (ECA) Regional Monitoring Blueprint v0.3 (East Channel Association and Emu Ltd., 2005). Multivariate analysis of the fish data in isolation (Fig. 2) suggests an association of the lower diversity western sites with lesser spotted dogfish, *Scyliorhinus canicula* and the red gurnard *Aspitrigla canicula*. The eastern area, characterised by *Ophiura albida* had concentrations of plaice *Pleuronectes platessa* and smooth hound, *Mustelus mustelus*. High abundance of *Trisopterus luscus* characterised the central portion of the ECR. The interpretation aligned reasonably well with the infauna and epifauna data from the Hammon Grab samples. Multivariate analysis of both the invertebrate and fish data from the 2 m epibenthic trawls further identified a *Trisopterus luscus* assemblage associated with the central eastern portion of the ECR. The 2 m data recorded a similar low abundance assemblage towards the western boundary characterised by *Asterias rubens* (Emu Ltd., 2008).

5. Sensitivities of species to entrainment

The identification of sensitivity and vulnerability of species to entrainment has adopted a similar approach to earlier sensitivity studies (MES, 2007) in identifying traits that would potentially affect the vulnerability of species' populations to aggregate dredging. Documented evidence of biological traits namely: sensitivity to dredging noise; burst speed and fecundity have been considered but, departing from the MES approach, behavioural traits associated with burial; and response to disturbance have been included that are considered material to assessing the sensitivity of fish species.

Table 1 lists the species/orders for which dredging entrainment data is available together with the trait information and an evaluation of the significance of the trait in affecting the sensitivity of populations to entrainment.

The absence of one of more ticks against traits does not necessarily reflect a reduced risk of entrainment as certain traits act independently of others. For example, evidence suggests that sandeels have quite a high burst speed but since the species are vulnerable owing to both episodic and seasonal burial traits, the relevance of burst speed is discounted (McGraw and Armstrong, 1990).

Table 1 restricts itself to those orders of species for which entrainment data exists and equivalent genera are found within the ECR. Since the species/orders of species listed are all potentially exposed to entrainment, the sensitivity index may also be considered as a vulnerability index. The vulnerability index is not intended to be exhaustive in terms of either species or traits. There are a range of fish species that are vulnerable to entrainment that are not found in the ECR, for example, migratory fish species in restricted estuarine areas (Carlin and Rogers, 2002; Reine and Clarke,

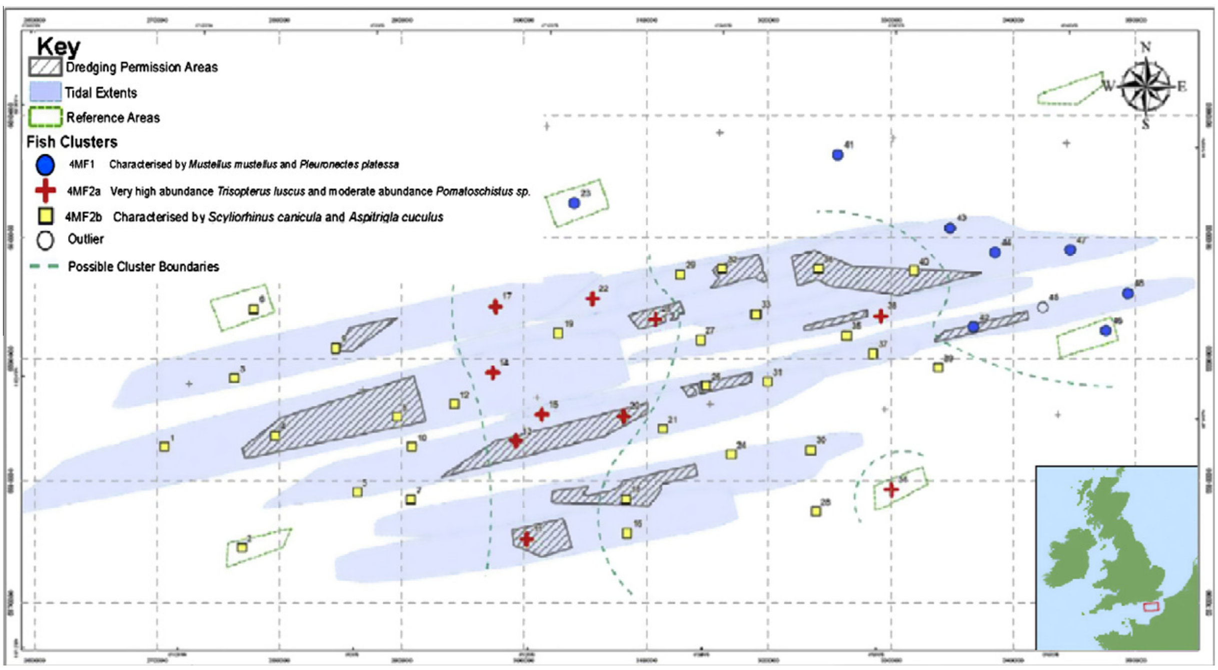

Fig. 2. Distribution of clusters derived from 4m beam trawl, 2005 (Source: East Channel Association and Emu Ltd., 2005).

Table 1
Sensitivity criteria for entrainment of marine species from hydraulic dredging.

	Sensitivity criteria – Marine species				
Key	√ = Evidence supports the relevance of this trait in potentially impacting the local species population X = No evidence found to suggest that this trait potentially impacts the local species population 0 = Evidence is inconclusive in demonstrating impacts on the local species population				
Species/order	Evidence from entrainment data	Low sensitivity to noise	Burst speed	Burial trait	Fecundity
Pleuronectidae/ Soleidae	√ Flatfish, especially English sole were a main component of fish entrained by the YAQUINA (hopper dredge) in 1986 (McGraw and Armstrong, 1990) *Solea solea* entrained in the cooling water intake system of Doel Nuclear Power plant (Maes et al., 2004) Entrainment of both Plueronectidae and Soleidae is common at Hinkely (Henderson and Bird, 2009)	√ *Solea solea* are non-specialists which have no swim bladder and therefore poor sensitivity to dredging noise. (Nedwell et al., 2004) In laboratory tests measuring response of various fish species, Flounder instinct was to hide - react to noise by staying motionless on the bottom, hence no avoidance reaction (Nedwell, 2008)	0 Assessment made of burst speeds based upon fish type characterised demersal bony flatfish as having a Medium burst speed (ABPmer, 2009)	√ *Solea solea* response to alarm is burial in the sediment (Dipper, 2001) increasing the likelihood of entrainment	X Both sole and plaice have relatively high fecundity, females producing ~500,000 eggs reducing the sensitivity of the population to loss of spawning adults Dab lay 150,000 eggs but breed earlier than sole or plaice Female Flounder lay between 500,000 and 2 million eggs
Scyliorhinus canicula and *Scyliorhinus stellaris*	√ Entrainment of spiny dogfish by pipe dredge, cited by Larson and McGraw and Armstrong, 1990. Instances of entrainment of both species at both at Oldbury, Berkley and Hinkley Point Cooling Water intakes. *S. canicula* is regularly caught at Hinkley (Henderson and Bird, 2009)	√ Dogfish lack a swim bladder and as elasmobranchs have poor sensitivity to dredging noise	√ Bottom dwelling sharks including dogfish and smooth hound characterised by low burst speed (ABPmer, 2009)	X	√ Low fecundity – eggs fertilised internally and laid individually
Sensitivity criteria – Marine species					
Ammodytes spp., *Hyperoplus lanceolatus*	√ Pacific sandlance *Ammodytes hexapterus* accounted for 92% of all individuals entrained during a four year study of navigation dredging entrainment (Larson and Moehl, 1990)	0 *Ammodytiae* are without a swim bladder. Little appears to be published on their hearing sensitivity but their diurnal and seasonal burial traits principally affect their vulnerability over any consideration of hearing	0 The principal vulnerability of *Ammodytiae* is considered to be in the buried state where burst speed would be irrelevant	√ Sandeels hibernate September to March (Macer, 1966; Wright et al., 2000) with the exception of spawning in December and January (Gauld and Hutcheon, 1990). Response to danger is burial (Dipper, 2001)	0 While the female can produce between 4000 and 20,000 eggs, the eggs may gestate in an area subject to dredging. Insufficient known about the potential impact of entrainment on stock levels
Clupea harengus	√ Larson and Moehl, 1990 recorded an entrainment rate of 0.008/cy over a 4 year study noting low entrainment for pelagic fishes Maes et al., 2004 recorded high numbers of herring entrained in the cooling water intake system of Doel Nuclear Power plant but a 94.7% reduction following the introduction of an acoustic fish deterrent system Avoidance of dredging during the herring spawning season November to March/April in the Eastern Channel areas has minimized risk to herring population	X Clupeoidea, including herring (*Clupea herringus*) and sprat (*Sprattus sprattus*), are hearing specialists (Nedwell et al., 2004) with high sensitivity to dredging noise that would normally result in early avoidance of the dredge zone	X Data not available but the sensitive hearing of herring and early avoidance renders this consideration less important	X	X Fecundity is relatively high. The issue of egg survival for herring in gravel habitats subject to dredging is acknowledged and addressed by existing mitigation measures

Sensitivity criteria – Marine species					
Gobiidae	√ Thirteen *Pomatoschistus pictus*, recorded in outwash samples by Lees et al., 1992	√ Gobies are relatively insensitive auditory generalists with best hearing within a narrow band ~100 Hz (Nedwell et al., 2004). Entrainment records suggest that they are insensitive to dredging noise	Not Known	X	X Gobiidae are fairly prolific batch spawners
Rajidae spp.	√ Entrainment rate of 0.003/cy Longnose skate, *Raja rhina*, and 0.001/cy recorded for Big skate, *Raja binoculata* by Larson and Moehl, 1990	√ Rajidae, do not have swim bladders. Based upon studies on *Raja clavata*, Rajidae are considered to have low sensitivity to noise increasing the likelihood of entrainment	0 Rays are considered to have a Medium burst speed classification (ABPmer, 2009). Given entrainment records, further investigation is required to either confirm or discount the significance of burst speed	X	√ Low fecundity combined with long slow life histories has rendered stocks of several species of Atlantic skate vulnerable (Jennings et al., 2000)
Sensitivity criteria – Marine species					
Scorpaeniformes including Triglidae	√ Pacific staghorn sculpin, *Leptocottus armatus* recorded rates vary from 0.003 to 0.092/cy. Variety of different species cited in entrainment records by Reine and Clarke, 1998. One red gurnard, *Aspitrigla cuculus* reported by Lees et al., 1992	√ The audiogram for Sea Robin (Triglidae family) shows the range of hearing sensitivity to be between 100 and 600 Hz over which range the species-specific hearing threshold peaks at 104 dB_{ht} (Nedwell et al., 2004 after Tavolga & Wodinsky (1963)). If this is consistent with other Scorpaeniformes then it can be concluded that fish of this order have relatively poor hearing sensitivity to dredging noise	Not known	X	X

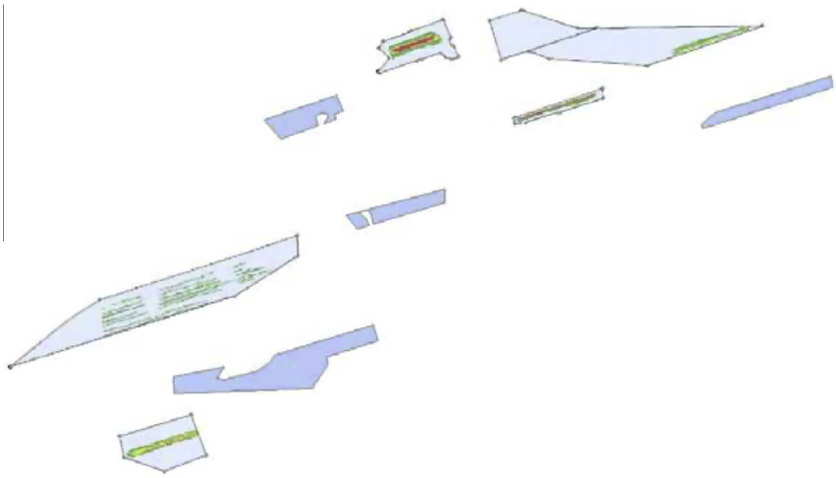

Fig. 3. ECA dredge areas showing EMS data superimposed upon licence areas.

1998). Further research in this area and of larval drift entrainment has been outside the scope of this study to fully investigate.

6. Estimation of entrainment rates

Estimates of entrainment have been made using the following:

- Electronic Monitoring System (EMS) data (ECA and Marine Space, 2008a,b, 2009, 2010);
- Typical dredging production rate and footprint; and
- Distribution data for vulnerable species based upon Table 1 and annual sampling data (Emu Ltd., 2005, 2006, 2007, 2008);

The processed monitoring data is all available from the East Channel Association web site (http://www.eastchannel.info/).

EMS data is published in hours of dredging per 50 m square. As the original track plots are not in the public domain, it has been necessary to estimate the total area of seabed covered by the draghead. In order to do this, the following assumptions have been made:

- An average speed of the draghead across the seabed of 2 knots;
- A draghead width of 1.4 m but impact width of 2.4 m;
- An average production rate of 470 kg/s; and
- Equivalent distances travelled by the draghead of 0.93, 2.8 and 4.63 km for the low, medium and high 50 × 50 m EMS grid squares respectively (see below).

The equivalent draghead distances are based upon an average speed of 2 knots, i.e. a distance travelled of 18.6 squares (930 m) in 15 min.

EMS data is recorded according to the time spent by the dredger in each 50 × 50 m cell and is graded as follows:

Low – <15 min per cell per year.
Medium – >15 min per cell per year <1 h 15 min.
High is >1 h 15 min per cell.

Typically, a dredger will dredge aligned to the tidal access. This pattern is clearly evident in the plot that shows EMS data for the ECR (see Fig. 3). Based upon a dredge speed of 2 knots it is reasonable to assume that the equivalent total distances travelled by the draghead equal to 0.93, 2.8 and >4.63 km for the Low, Medium and High intensity EMS squares respectively.

Theoretical flow fields estimates for suction dredgers (Fig. 4) indicate that the flow velocity at 0.5 m from the draghead is still in excess of 1.0 m/s for a typical 0.7 m diameter dredge pipe (Clausner and Jones, 2009) and is likely to exceed the burst speed

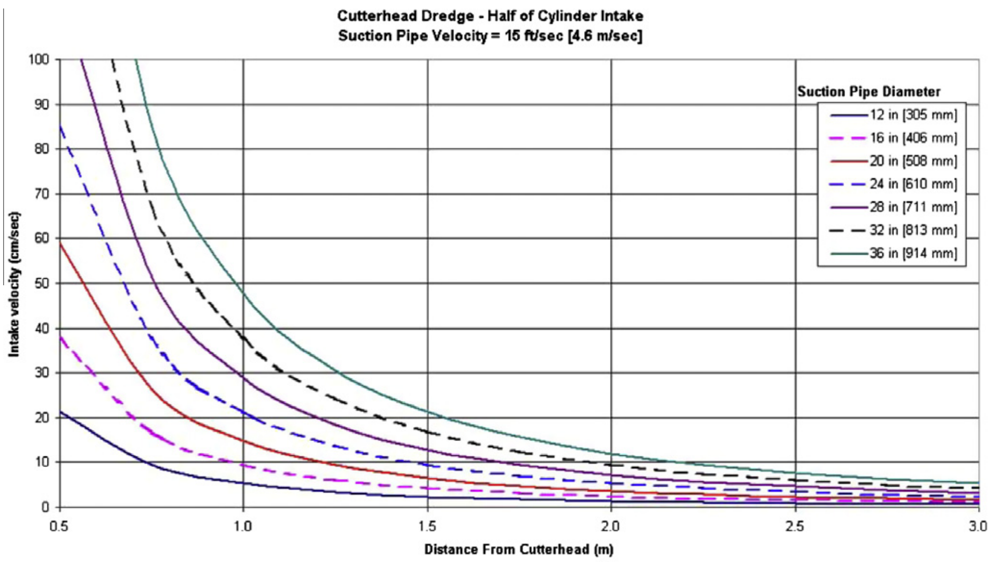

Fig. 4. Predicted flow field for a cutter suction draghead. (Source: Clausner and Jones, 2009 –USACE DOER Program).

Table 2
Derivation of draghead footprint in Eastern Channel Areas for 2008.

Dredging Intensity	Area of Intensity Polygon km^2	Area of Intensity Polygon m^2	No of 50x50 cells	Multiplier draghead line distance (km)	Distance travelled by draghead (km)	Atrea covered by draghead m^2	Conversion to nautical miles	Estd. Hours Dredging	Estd. Production (tonnes)
		Dredge Area 461					0.5396		
LOW	0.857	857000	342.8	0.93	318.804	765129.6			
MEDIUM	0.7275	727500	291	2.8	814.8	765129.6			
HIGH	0.1475	147500	59	4.63	273.17	655608			
Total					1406.774	3376257.6	759.10	379.5	642194.582
		Dredge Area 473							
LOW	1.075	1075000	430	0.93	399.9	959760			
MEDIUM	0.4075	407500	163	2.8	456.4	1095360			
HIGH	0.54	540000	216	4.63	1000.08	2400192			
Total					1856.38	4455312	1001.70	500.9	847440.44
						0			
		Dredge Area 474				0			
LOW	0.545	545000	218	0.93	202.74	486576			
MEDIUM	0.1375	137500	55	2.8	154	369600			
HIGH	0.3075	307500	123	4.63	569.49	1366776			
Total					926.23	2222952	499.79	249.9	422825.477
		Dredge Area 464/458							
LOW	0.7775	777500	311	0.93	289.23	694152			
MEDIUM	0.285	285000	114	2.8	319.2	766080			
HIGH	0	0	0	4.63	0	0			
Total					608.43	1460232	328.31	164.2	277749.268
		Dredge Area 478							
LOW	0.1725	172500	69	0.93	64.17	154008			
MEDIUM	0	0	0	2.8	0				
HIGH	0	0	0	4.63	0				
Total					64.17	154008	34.63	17.3	29293.7077
						0			
		Dredge Area 475				0			
LOW	0	0	0	0.93	0	0			
MEDIUM	0	0	0	2.8	0	0			
HIGH	0	0	0	4.63	0	0			
Total					0	0	0.00	0.0	0
						0			
Year Total						11668761.6	Total Estd. Tonnage		2219503.48
							Equals2.21 Mtonnes[a]		

[a] Actual extraction was 2.25 million tonnes.

for most of the vulnerable species listed in Table 1. On this basis an impact width of 2.4 m is considered realistic for typical aggregate dredging operations.

Overall areas for the Low, Medium and High intensity dredging categories are provided for each aggregate licence area from published ECA data. By converting these to equivalent distances and multiplying by the draghead impact width of 2.4 m an estimate was made of the area of seabed impacted.

In order to validate the approach and assumptions, a check was made of whether the estimated distance travelled by the draghead at 2 knots and an average production rate of 470 kg/s approximated the overall published annual production. The production estimate derived from the EMS/speed/production data was found to be within 98% accuracy of the actual production. It is concluded that the estimated distance travelled by the draghead and therefore the basis for the footprint calculation is accurate.

The workings for the calculation of draghead footprint for 2008 are shown in Table 2.

7. Results

Summary results for 2008 are shown in Table 3. Two sets of entrainment totals are shown: the first in column 4 is based upon the average of the sampled species populations from the trawl data and the estimated total area covered by the draghead from Table 2; an additional entrainment rate (column 5) has been calculated based upon a total estimated production (from Table 2) applying average production rates supplied by the industry; the second total in the final column is based upon the entrainment rate and the actual published total production from the ECR in 2008 of 2.25 million tonnes. The similarity in the values reflects the closeness with which production calculated from EMS data reflects the industry published results.

8. Discussion

The projected entrainment rates published here are currently based upon theoretical assumptions; comparison of these values against measured entrainment rates is required to test the robustness of the analysis. There are clearly limitations in validating the projected entrainment rates because the detailed studies for which data is available are confined to the Columbia River Estuary on the north east coast of the USA, where both species composition and abundance are very different to the ECR. Cognisant of these limitations, a comparison of the entrainment rates in Table 3 with previously published entrainment rates (Reine and Clarke, 1998) confirms that the projected rates for flatfish, 0.001 for sole and 0.001 for plaice are in a similar range.

The projected entrainment rates for Scorpaeniformes, Red gurnard 0.011 and Tub gurnard, 0.006, are generally an order of magnitude higher than those reported by Reine and Clarke although Streaked gurnard 0.002 and pogge 0.002 are comparative. Projected rates for lesser spotted dogfish 0.013 are higher relative to the rates quoted for elasmobranch species (<0.01–0.008) but values for Smooth hound are similar and those for other species, Thornback ray, Starry smooth hound and Bull huss are lower.

Table 3
Projected estimates of fish entrained based upon study assumptions and total production.

1 Taxon	2 Common name	3 Average density/m^2	4 Est. fish entrained (draghead footprint)	5 Entrainment rate/m^3 (projected production)	6 Est. fish entrained (total production)
			11668761.6	2213245.751	22,50,000
Trisopterus luscus	Bib	0.0046	53,338	0.0241	54,224
Scyliorhinus canicula	Lesser spotted dogfish	0.0024	28,450	0.0129	28,923
Aspitrigla cuculus	Red Gurnard	0.0020	23,791	0.0107	24,186
Callionymus lyra	Dragonet	0.0017	20,282	0.0092	20,619
Trigla lucerna	Tub Gurnard	0.0011	13,363	0.0060	13,585
Pomatoschistus sp.	Gobidae	0.0003	4007	0.0018	4074
Mustelus mustelus	Smooth Hound	0.0003	3023	0.0014	3073
Trigloporus lastoviza	Streaked Gurnard	0.0004	4973	0.0022	5055
Solea solea	Dover Sole	0.0002	2247	0.0010	2284
Pleuronectes platessa	Plaice	0.0002	2229	0.0010	2266
Agonus cataphractus	Pogge	0.0003	3393	0.0015	3449
Trisopterus minutus	Poor Cod	0.0013	14,637	0.0066	14,880
Diplecogaster bimaculata	Two-spotted clingfish	0.0001	1671	0.0008	1699
Scyliorhinus stellaris	Bull Huss	0.00007	839	0.0004	853
Raja clavata	Thornback ray	0.0001	1280	0.0006	1301
Mustelus asterias	Starry smooth hound	0.00005	607	0.0003	618
Scophthalmus rhombus	Brill	0.00003	370	0.0002	376
Buglossidium luteum (juv.)	Solenette	0.00003	296	0.0001	301
Blennius ocellarius	Butterfly blennie	0.00005	594	0.0003	604
Microstomus kitt	Lemon sole	0.0002	1810	0.0008	1840
Phrynorhombus regis	Norwegian topknot	0.00008	907	0.0004	922
Lophius piscatorius	Angler fish	0.00002	179	0.0001	182
Gobiidae spp.	Gobies	0.0006	6886	0.0031	7001
Microchirus varigatus	Thickback sole	0.0004	4894	0.0022	4975
Ctenolabrus rupestris	Goldsinny	0.00001	148	0.0001	150
Trachinus draco	Greater weaver	0.00004	413	0.0002	420
Echiichthys vipera	Lesser weaver	0.00004	441	0.0002	448
Hyperoplus lanceolatus	Greater sandeel	0.00002	275	0.0001	279
Zeus faber	John Dory	0.00004	469	0.0002	477
Sygnathus rubescens	Pipefish species	0.00001	62	0.0000	63
Triglidae sp. (juv.)	Gurnards (juv,)	0.000004	48	0.0000	0
Mullus surmuletus	Red mullet	0.00001	109	0.0000	0
Arnoglossus laterna	Scaldfish	0.000003	39	0.0000	0
Limanda limanda	Dab	0.00001	100	0.0000	101
Solea lascaris	Black/flounder flounder	0.00003	319	0.0001	324
Liparis liparis	Sea snail	0.00001	102	0.0000	104

Table 4
Projected entrainment rates based upon Lees et al. (1992).

Species	Sample from 50 min (aggregate)	Entrainment rate (production tonnes) 1410
Two spotted Clingfish *Diplecogaster bimaculata*	5	0.004
Dragonet *Callionymus lyra*	4	0.003
Painted gobies *Pomatoschistus pictus*	13	0.009

Henderson and Bird (2009) – after Elliott (2007) has grouped Triglidae, *Scyliorhinus caniculus* and *C. lyra* 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 owing to their general intolerance of reduced salinity. It is understandable, therefore, that the densities and entrainment rates for these fish within the ECR may be higher than those reported in the Columbia River Estuary studies.

Accepting that the contexts are geographically remote, there is correspondence between the empirical entrainment rates from the Columbia River and the projected entrainment rates for the ECR.

The entrainment sampling undertaken in the Eastern English Channel is far more limited than that undertaken on the Columbia river being based upon just 5 × 10 min samples. Nevertheless, it provides an indication of potential entrainment rates for the fish sampled. Table 4 lists the three species sampled from the spillways together with the entrainment rates aggregated over 50 mins of production.

The one investigation providing entrainment data for aggregate dredging in the English Channel further validates the projected entrainment rates.

There is acknowledgement that dredging causes entrainment to fish/shellfish through direct uptake but the likelihood of population-scale impacts has been viewed as low for commercially important adult stocks. By contrast impacts upon the wider benthic fish community, breeding/spawning grounds, nursery grounds, and overwintering grounds for crustacean are viewed as potentially very high (Carlin and Rogers, 2002). Management of aggregate dredging activity in the UK has reflected these early assessments of impact upon commercial fisheries. A low level of impact upon fish stocks is envisaged and accepted but additional licence conditions are put in place to protect particularly sensitive lifecycle phases. Thus, licence conditions restrict aggregate dredging at areas 461 and 478 to the period March to October inclusive so as to avoid disturbance during winter herring spawning season. Similarly at Area 366–370 on the Hastings Shingle Bank, dredging activity is terminated for the duration of the period of inshore migration of adult sole to the breeding/nursery grounds (usually from the beginning of March to the end of April) as a precautionary measure to safeguard the sole population and viability of the fishery.

Operations within the ECR represented a positive new departure for management of aggregate extraction which, for the first time, was approached at a regional rather than a licence area level. Prior to 2006 aggregate dredging had not occurred in the ECR; monitoring of the seabed during dredging activity can therefore be compared with a baseline unaffected by dredging. The inclusion of 4m beam trawl and scallop dredge surveys allows the effects of dredging upon commercially important shellfish and demersal fish species to be monitored.

Independent analysis of the fish assemblages suggests reductions in abundance have occurred for a number of species since 2006 unrelated to natural environmental stimuli or commercial fishing effort. Furthermore, interruptions to recruitment in the ECR plaice and sole populations have been observed that are not reflected in the wider ICES data (Drabble, 2010).

The findings strengthen the case for entrainment surveys as part of impact monitoring for marine aggregate dredging.

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References

ABPmer, 2009. Collision Risk of Avoidance with Wave and Tidal Devices. Report commissioned by RPS on behalf of the Welsh Assembly Government.
Armstrong, D.A., Stevens, B. G., Hoeman, J.C., 1982. Distribution and abundance of Dungeness crab and Crangon shrimp, and dredging-related mortality of invertebrates and fish in Grays Harbor, Washington. Tech. Rep. for Washington Department of Fisheries and U.S. Army Corps of Engineers, Seattle District by School of Fisheries, University of Washington, Seattle, p. 349.
Carlin, D., Rogers, S (2002) A Procedure to Assess the Effects of Dredging on Commercial Fisheries. Prepared by CEFAS Lowestoft in support of CSG Contract A0253.
Clausner, J.E. and Jones, D.L., 2009. Prediction of Flow Fields, Near the Intakes of Hydraulic Dredges USACE DOER Program [Internet: http://el.erdc.usace.army.mil/dots/doer/flowfields/dtb350.html] accessed 28 Feb.
Drabble, R.C., 2012. Monitoring of east channel dredge areas benthic fish populations and its implications. Marine Pollution Bulletin 64, 363–372.
Dipper (2001) British Sea Fishes. Underwater World Publications.
ECA and Marine Space, 2008a. East Channel Region Dredging Activity Report – 2006 Activity. Volume 1, Issue.
ECA and MarineSpace. 2008b. East Channel Region Dredging Activity Report – 2007 Activity. Volume 1, Issue.
ECA and MarineSpace. 2009. East Channel Region Dredging Activity Report – 2008 Activity. Volume 1, Issue.
ECA and MarineSpace. 2010. East Channel Region Dredging Activity Report – 2009 Activity. Volume 1, Issue.
Elliott, M., Whitfield, A.K., Potter, I.C., Blaber, S.J.M., Cyrus, D.P., Nordlie, F.G., Harrison, T.D., 2007. The guild approach to categorizing estuarine fish assemblages: a global review. Fish and Fisheries 8, 241–268.
Emu Ltd., 2004. EEC Benthic Survey Specification. Report presented to the Eastern Channel Association, Emu Ltd. Durley.
Emu Ltd., 2005. 4m beam trawl monitoring data file: Abundance for all species by trawl site given per 1000m trawl length: J PRIMER ready species list.xls.
Emu Ltd., 2006. 4m beam trawl monitoring data file: Abundance for all species by trawl site given per 1000m trawl length: D_Full Species List from 4m Beam Trawl (CD).2006.xls.
Emu Ltd., 2007. 4m beam trawl monitoring data file: Abundance for all species by trawl site given per 1000m trawl length: K PRIMER Ready Species List (Final).2007.xls.
Emu Ltd., 2008. 4m beam trawl monitoring data file: Abundance for all species by trawl site given per 1000m trawl length: J PRIMER Ready Species List2008.xls.
East Channel Association and Emu Ltd., 2005. ECA Regional Monitoring Blueprint v0.3.
Gauld, J.A., Hutcheon, J.R., 1990. Spawning and fecundity in the lesser Sandeel in the north-western North Sea. J. Fish Biol. 36, 611–613.
Henderson, P.A., Bird, D.J., 2009. Fish and macro-crustacean communities and their dynamics in the Severn Estuary. Marine Pollution Bulletin 61 (2010), 100–114.
Highley, D.E., Hetherington, L.E., Brown, T.J., Harrison, D.J., and Jenkins, G.O., 2007. The Strategic Importance of the Marine Aggregate Industry to the UK. British Geological Survey Research Report 0R/07/019.
Jennings, S., Kaiser, M.J. and Reynolds, J.D. 2000. Marine Fisheries Ecology. Blackwell Science.
Larson, K., Moehl, C., 1990. Fish Entrainment by Dredges in Grays Harbor, Washington. In: Simenstad, C.A. (Ed.), Effects of Dredging on Anadromous Pacific Coast Fishes. Washington Sea Grant, Program University of Washington.
Lees, PG., Kenny, A., and Pearson, R., 1992. The condition of benthic fauna in suction dredger outwash: initial findings. Annex submitted to the report of the ICES working group on the effects of extraction of marine sediments on fisheries.
Maes, J., Turnpenny, W.H., Lambert, D.R., Nedwell, J.R., Parmentiers, A., and Ollevier, F., 2004. Field evaluation of a sound system to reduce estuarine fish intake at a power plant cooling water inlet. Journal of Fish Biology (2004) 64, 938-946.
Macer, C.T., 1966. Sandeels (Ammodytidae) in the south-western North Sea their biology and fishery. Fishery Invest. London. Ser. 2, 1–55.
Marine Ecological Surveys Ltd. (MES) 2007. Predictive framework for assessment of recoverability of marine benthic communities following cessation of marine aggregate dredging. Technical Report to the Centre for Fisheries and Aquaculture Science (Cefas) and the Department for Environment, Food and Rural Affairs (Defra). Project No MEPF 04/02.
McGraw, K.A., Armstrong, D.A., 1990. Fish Entrainment by Dredges in Grays Harbor, Washington. In: Simenstad, C.A. (Ed.), Effects of dredging on anadromous Pacific Coast fishes. Washington Sea Grant Program, University of Washington, Seattle.
Nedwell, J.R., Edwards, B., Turnpenny, A.W.H., Gordon, J., 2004. Fish and Marine Mammal Audiograms: A summary of available information. Subacoustech Report ref: 534R0214.
Nedwell, J.R., 2008. The dBht; a metric for assessing the behavioural and auditory effects of underwater noise. Subacoustech Report No. 60 R 0704Subacoustech Report No. 60 R 0704.
Newell, R.C., Seiderer, J.L., Hitchcock, D.R., 1998. The impact of dredging works in coastal waters: a review of sensitivity to disturbance and subsequent recovery of biological resources on the seabed. Oceanography and Marine Biology: an Annual Review 1998 (36), 127–178.
Reine, K., Clarke, D., 1998. "Entrainment by hydraulic dredges–A review of potential impacts". Technical Note DOER-E1. US Army Engineer Research and Development Center, Vicksburg, MS.
Royal Haskoning, 2003. Regional Environmental Assessment for Aggregate Extraction in the Eastern English Channel Non-Technical Summary.
Tavolga, W.N., Wodinsky, J., 1963. Auditory capacities in fishes. Bulletin of the American Museum of Natural History 126, 177–240.