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Organic Enrichment Associated with Outwash from Marine Aggregates Dredging: A Probable explanation for Surface Sheens and Enhanced Benthic Production in the Vicinity of Dredging Operations.

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Most recent studies of dispersion of sediment plumes generated by marine aggregates dredging, including those reported here, suggest that the area of impact of outwash from dredging activities is smaller than estimates based on Gaussian diffusion models, especially when the proportion of silt and clay in the deposits is low. There is, however, often a relatively larger zone of visible impact which can extend for several kilometers downstream from a dredger during normal loading operations. This paper presents evidence which suggests that the "far field" visibility of the dispersing plume is associated with organic enrichment derived from fragmented marine benthos discharged with the outwash water.

The values which we have recorded for unexploited deposits off Southwold, Suffolk are as high as 1.454 g/l AFDW (ash-free dry weight) of which 0.007 g/l (0.48%) comprises lipids. Such material appears to be of sufficient concentration to match the likely removal of benthos from the sediments by the dredgehead. Even allowing for the dispersion which must occur downstream from the dredger, it seems likely that the organic enrichment derived from fragmented invertebrates in the dredger outwash may account for the enhanced species diversity and population density of benthic invertebrates recorded by others beyond the boundaries of dredged areas.

Introduction

The increased exploitation of marine deposits for aggregates, and the physical and biological impacts of dredging works has been widely reviewed (Dickson & Lee, 1972; Shelton & Rolfe, 1972; Cruikshank & Hess, 1975; de Groot, 1986; Nunny & Chillingworth, 1986; ICES, 1993; Newell et al, 1998). Essentially, the physical impact of dredging works is dependent partly on the method of dredging, and partly on the amount and grade of deposits rejected by screening, and overspill from the hopper. A typical modem sea-going aggregates dredger operating in U.K. waters is self-contained and uses a centrifugal pump delivering approximately 7750 m^3 h^{-1} to lift the aggregates from the sea bed into a hopper of approximately 5,000 t capacity, a process which takes 2-8h depending on the amount of screening which is required to attain a cargo load of suitable quality.

Estimates by Hitchcock & Drucker (1996) suggest that for a suction trailer dredger of 4,500 t hopper capacity operating on the Owers Bank, off the south coast of U.K., approximately 750 t of solids are discharged through overspill and as much as 7,223 t through the screening reject chutes. Water discharge is 21,387 t from overspill and 13,499 t through screening. The screened material is thus discharged in relatively high concentration through a reject chute whilst a larger volume containing a relatively low concentration of suspended solids overflows from the hopper.

In its simplest form, the settlement velocity and residence time of particles discharged during screening and from hopper overflow can be estimated from Stoke's law. If the residence time of particles in the water column is known, the duration and speed of local currents and turbulence will then determine the excursion pattern before settlement. Estimates of dispersion of material based on these Gaussian diffusion principles suggest that coarse material settles rapidly below the point of discharge from the dredger, a feature which has been verified in studies at sea (Gajewski & Uscinowicz, 1993). Very fine sand particles have been estimated to travel up to 11 km from a dredge site at Owers Bank off the south coast of U.K whilst similar estimates based on Gaussian diffusion models for fine silt particles (<0.063 mm) suggest that this material could remain in suspension for up to 4-5 tidal cycles and be carried for as much as 20-km from the point source of discharge (H R Wallingford, 1993; cited in Hitchcock & Drucker, 1996).

Most recent studies on the dispersion of sediment plumes generated by marine aggregates dredging suggest, however, that the area of impact of outwash from dredging activities is smaller than estimates based on Gaussian diffusion models, especially when the proportion of silt and clay in the deposits is low. This appears to be due to complex cohesive properties of the discharged sediment particles that settle on the sea bed as a density current and reflects flocculation and initial entry velocity of the overspill/reject mixtures into the water column. The discharged material thus does not conform to settlement rates based on specific gravity and size of the component particles themselves (Land et al, 1994; Whiteside et al, 1995; Hitchcock & Deamaley, 1995; Hitchcock & Drucker, 1996). Such studies show that settlement of the inorganic particulate load discharged from marine aggregates dredging is mainly confined to a distance of a few hundred metres from the point source of discharge. The surface plume is, however, visible as a "slick" for a considerable distance beyond that at which suspended inorganic solids have fallen to background levels. This has been ascribed to the possibility of air bubbles and entrainment of organic matter into the water column from the dredging process (Hitchcock & Drucker, 1996).

It is the purpose of this paper to present evidence which shows that this "far field" visibility of the dispersing plume is associated with organic enrichment probably derived from fragmented marine benthos discharged with outwash water. Such material appears to be of sufficient concentration to match the known removal of benthos from the dredged deposits, and may account for the enhanced benthic species diversity and population density reported for deposits surrounding dredged areas (see Poiner & Kennedy, 1984).

Material and Methods

Continuous Backscatter Profiling (CBP)

Acoustic Doppler current profiling techniques utilise the transmission of a beam of sound into the water column by 3 or 4 highly directional (2.5^0 beam width) transducers arranged in a “Janus” configuration, inclined at 30^0 to the vertical. Backscattered sound from plankton, small particles, air bubbles and small-scale heterogeneities in the water (“scatterers”) are recorded by the transducer. The primary function of Doppler current profiling techniques is to record continuous current velocities through depth and, depending on the equipment, dynamically using a moving boat. This technique is widely used and is gaining increasing acceptance worldwide. A secondary function of some systems enables the operator to display the acoustic strength of the returned signals as affected by the suspended particulate matter, and hence record variations in scatterers, generally interpreted as suspended solids concentrations (see Land *et al*, 1994; Whiteside *et al*, 1995; Weiergang *et al*, 1995).

Acoustic backscatter transects reported in our study were obtained using an RDInstruments 1200 kHz Broadband Acoustic Doppler Current Profiler (ADCP^{TM}) which was operated from a survey vessel downstream of a marine aggregates dredger during normal loading operations on the Owers Bank, off the south coast of U.K. during 1995. Additional samples of the composition of the outwash to verify the predictions made from the Owers Bank data were obtained from a dredger operating off Southwold, Suffolk in April 1998 (see Fig. 1). Doppler current profiling techniques and acoustic backscatter measurements have been used extensively for observation of the distribution of suspended particulate matter, particularly zooplankton following the work of Flagg & Smith (1989). Similar techniques have recently been used for observations on suspended solids associated with dredging and dredged material disposal operations, particularly cohesive sediments (Thevenot & Kraus, 1993).

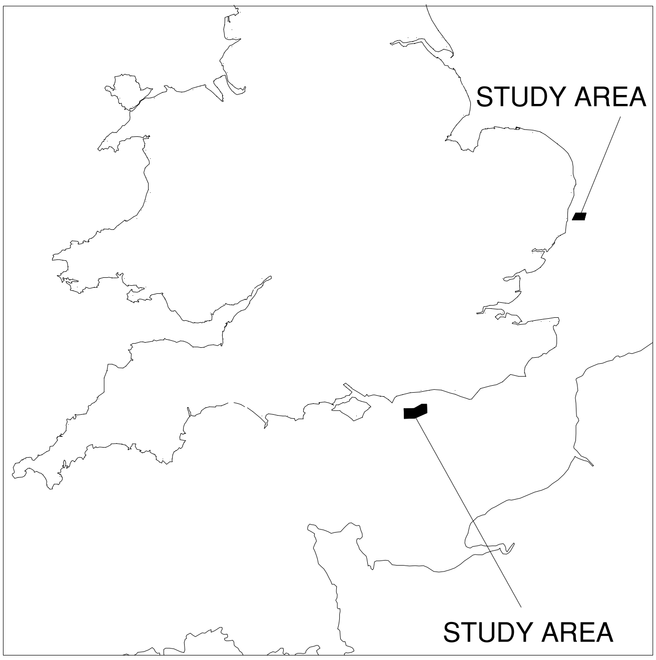

Fig.1 Map of the southern part of the UK showing the position of the two areas at which surveys were carried out

A number of investigators have attempted to correlate backscatter sound strength (dB) of the returned signal with suspended solids concentration (mg/l) with varying degrees of success (Thevenot & Johnson, 1994; Tubman *et al*, 1994). Land *et al* (1994) reported statistically acceptable correlation with optical silt meters and water samples for sediments in the range of 5-75 µm with a mean particle diameter of 10 µm and concentrations up to 1000 mg/l. Lohrmann & Huhta (In: Tubman *et al,* 1994) calibrated a 2.4 mHz Broadband ADCP™ in a purpose-built laboratory calibration tank using material obtained by grab from the sea bed of the site to be studied. Although suspended solids concentrations determined by the ADCP™ were considered to agree “reasonably well” with the water sample analysis, the maximum error was considered to be ± 60% at 50 mg/l. Thevenot & Johnson (1994) suggest that flocculation of the material could be a contributing factor to the differences between field and laboratory calibrations. Detailed discussion of the principles of using the acoustic backscatter function of the ADCP™ can be found in Land *et al* (1994) and Weiergang *et al* (1995).

In the study reported here, the acoustic backscatter function of the ADCP™ has been used to display a real-time semi-quantitative graphical representation of the gross morphology of the plume in relation to distance and water depth across a number of plumes generated by dredgers operating on the Owers Bank, off the south coast of U.K (see also Hitchcock & Deamaley, 1995; Hitchcock & Drucker, 1996; Hitchcock, 1997). Continuous observations of the strength of acoustic signal returned by particles in the water column were processed in real-time on screen displays with horizontal time and vertical water depth axes. The colouring of the individual boxes of data shown in Figs. 2 and 3 are user-configurable and relative to the acoustic strength of the returned echoes, and hence to the amount of “scatterers” in the water column. Importantly, this may include organic and inorganic particulates, air bubbles etc, so that complementary samples of suspended solids are required to interpret the plume morphology.

Broadband 1200 kHz ADCP™ techniques do not return valid data within the lowest 6% of the water column. Within the context of this paper, our observations do not include this boundary region of the water column. A different approach is required in order to assess the behaviour of suspended and settling material within such a layer at the sediment-water interface.

Positions of the Survey Data

The position of both the survey vessel and the dredger was fixed by Global Positioning System (GPS) techniques operating in Differential mode (dGPS). A position accuracy of better than 5 m was attained for both survey vessel and operating dredger.

Suspended Solids

Water samples were taken from the hopper spillways by three successive dips of a 20 litre bucket lowered directly into the flow, taking care not to obtain more than 3 litres of sample, and transferred to a single 10 litre container. A series of samples were taken at known times during the entire loading process and gave an even spread of data throughout the load. Separate samples of up to 2 litres of overspill water were taken for organic analysis. Due to difficulties of sampling in the high velocity flow from the screening reject chutes, direct measurements on material discharged by this route are the subject of a further field experiment to be conducted in the near future.

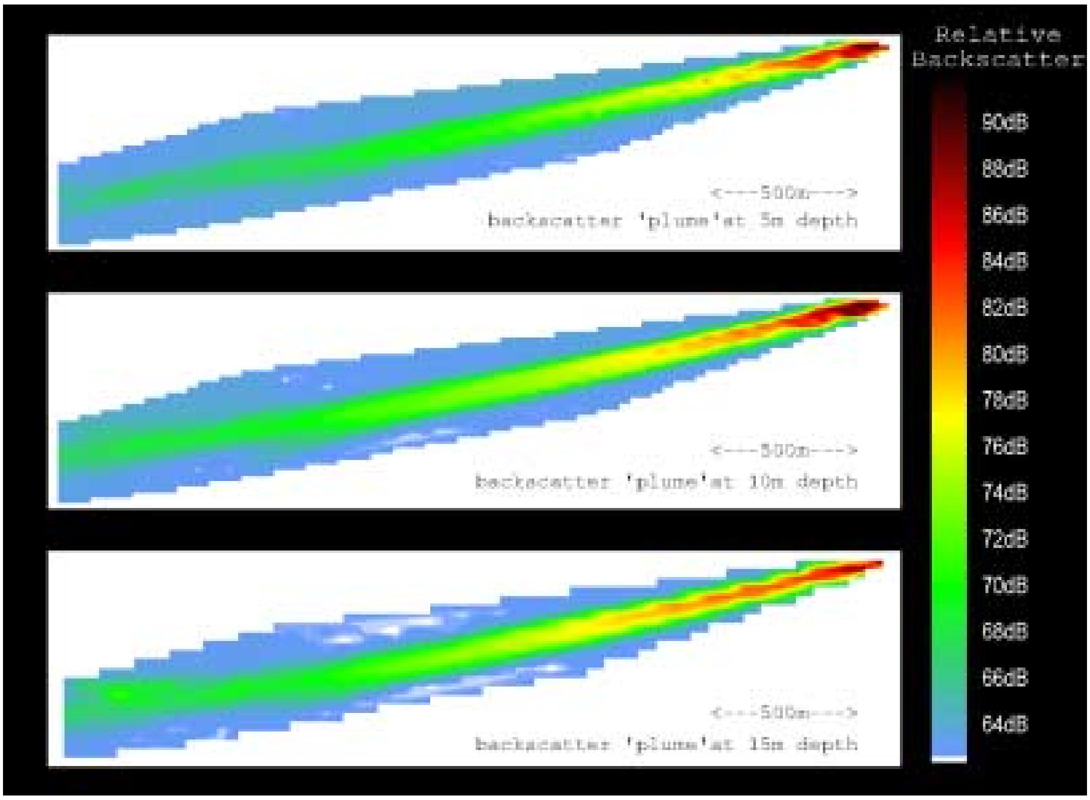

Fig 2. Relative acoustic backscatter interpolated between nine successive transects in relation to a suction hopper dredger *City of Rochester* operating whilst anchored on the Owers Bank off the south coast of the UK on 21st August 1995. Data are for depths of 5,10 and 15m below the sea surface.

Two samples of approximately 2 litres of sea water were taken at depths of 4m, 8m, 12m, 16 m and 18m depth at varying distances up to 3.5 km downstream of an operating dredger and the size distribution of suspended solids determined by standard gravimetric techniques (see also Hitchcock & Deamaley, 1994; Hitchcock & Drucker, 1996; Hitchcock, 1997). These data were then compared with background samples taken each day before dredging commenced, and with samples taken upstream of the dredger. Background suspended solids concentrations were between 5- 10 mg/l.

Ash-Free Dry Weight

Water samples of approximately 2 litres were collected from the hopper spillways and immediately deep-frozen in plastic containers. These were then transported frozen to the laboratory for analysis. The water samples were filtered through pre-weighed GF/F filters to remove the sedimentary particles > 0.7 µm in diameter. The sediments were dried in an oven at 40^0 C until a constant weight was achieved. The filters were then heated in a muffle furnace to 500^0 C for 24 h. The ash-free dried weight was calculated from the difference between the sediment weights.

Lipid Analysis

Water samples collected and deep-frozen as described above were filtered through a glass fibre filter to remove the suspended solids in the sample. The volume extracted was recorded before beginning the filtration process. The water sample was then double extracted into dichloromethane, concentrated on a rotary evaporator, and blown down to dryness under a stream of nitrogen. The sediments were also extracted using dichloromethane and these extracts were combined with the lipids from the water.

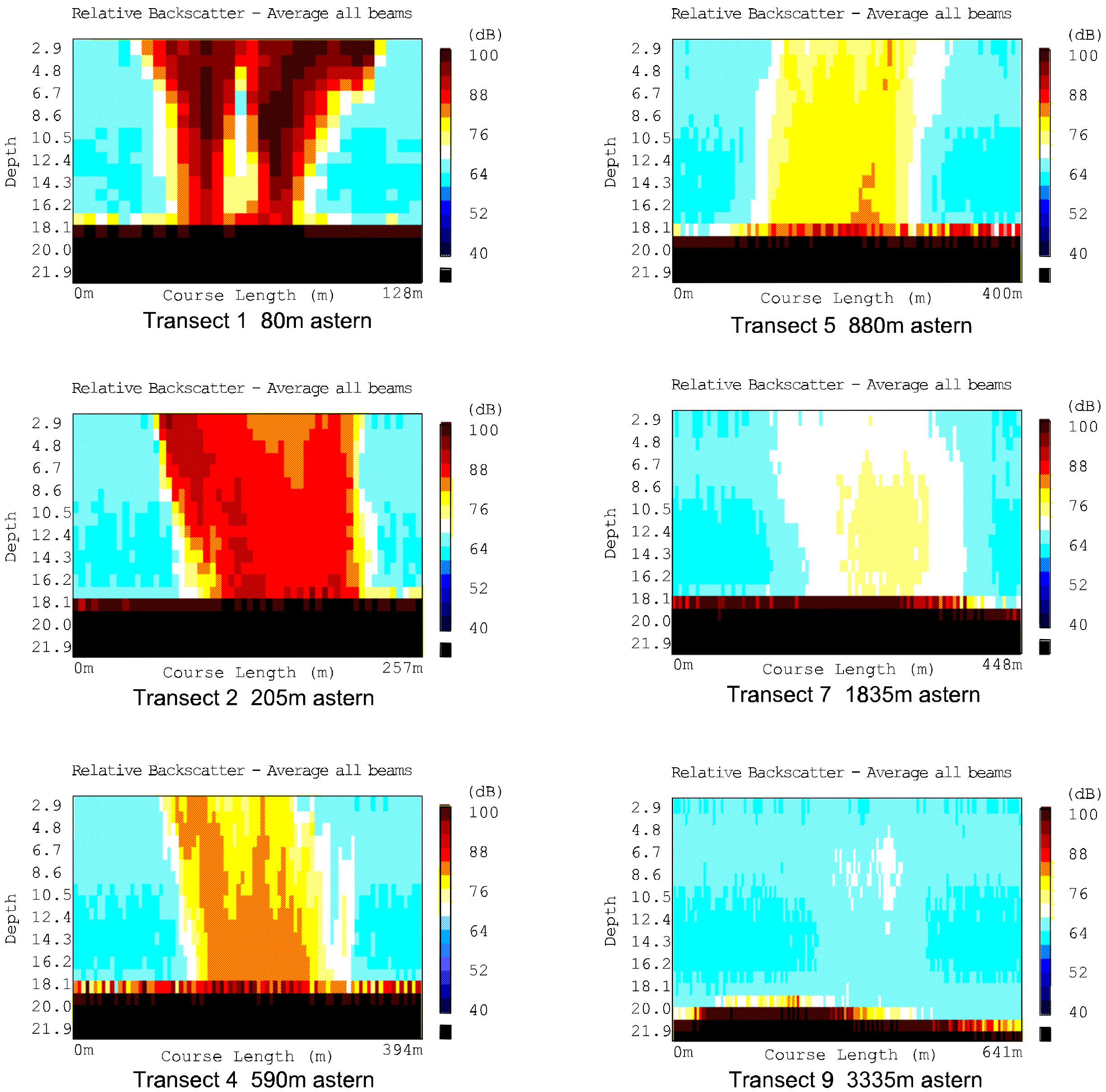

Fig 3. Vertical depth profiles for relative acoustic backscatter at varying distances downstream of a suction hopper dredger *City of Rochester* operating whilst anchored on the Owers Bank off the south coast of the UK on 21st August 1995. Note that the relative backscatter is detectable at distances as far as 3335m astern of the dredger, well beyond distances at which the suspended solids are insignificantly different from background levels (see Fig. 4)

Data Processing

The RD Instruments' data acquisition software "Transect" is used to generate many of the graphics of relative backscatter and current velocity. However, in order to assess depth-related variations of relative acoustic backscatter, current velocity and current direction, two in-house software routines have been developed in order to further analyse the ASCII output from the Transect software. These are Velocity MAP (VMAP) and Backscatter MAP (BMAP). The latter program is concerned with analysis of depth relative variation of the relative backscatter recorded by the ADCP^{TM}. Processing of the Transect files involves generating an ASCII file which contains, in tabular format, all the easting, northing, depth and relative backscatter values, as well as all other system and observed variables. These are then modelled using a simple contouring package to produce pixilated images of the contoured relative backscatter levels at required depths for comparison (see Hitchcock, 1997).

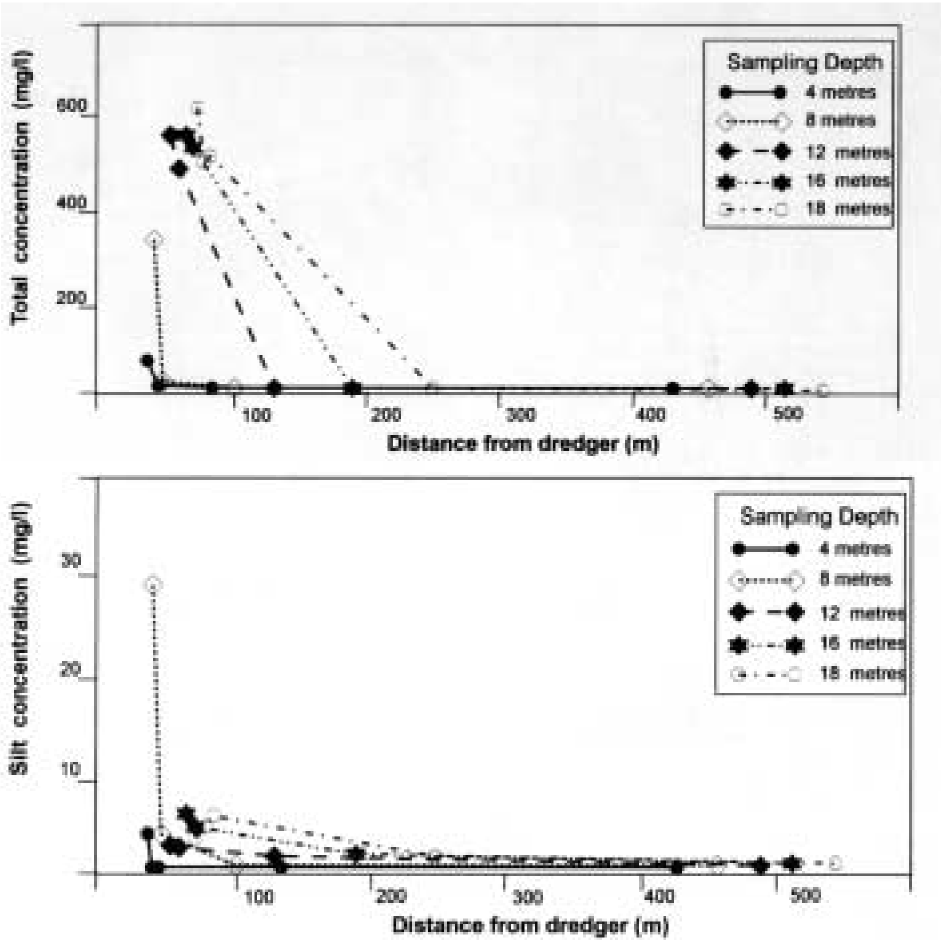

Fig. 4 The total concentration of suspended solids (top) and concentration of silt-sized (<0.063mm) material (bottom) in the water column at different depths and distances from the dredger measured by water sampling and optical tramsmissometers. (After Hitchcock and Drucker, 1996).

Results

Definition of plume morphology

The results of a plume monitoring programme carried out behind a trailing suction hopper dredger TSHD *City* of *Rochester* operating whilst anchored on 21st August 1995 are summarized in Figures 2-4. The Acoustic Backscatter Transects were obtained using an RDI 1200kHz Broadband Acoustic Doppler Current Profiler (ADCP). A series of 9 transects was recorded across the plume. Simultaneous current measurements analysed at the start and end of the transect indicate a mean surface flow of 53 cm/sec reducing to 36 cm/sec and a mean bottom flow of 35 cm/s reducing to 23 cm/s in a direction of 250 degrees. Water sampling data indicate that at less than 100 m from the dredger, total suspended solids concentrations were 480-611 mg/l in the lower water column and 80-340 mg/l in the upper water column.

Fig.2 shows the distribution of the transects and the horizontal distribution of contours of relative backscatter in relation to the dredger, at depths of 5m, 10m and 15m below the surface. The corresponding vertical depth profiles at varying distances up to 3,350 metres astern of the dredger are shown in Fig.3.

The variation of suspended sediment concentration measured independently by water sampling at various depths and with distance behind the dredger is shown in Figure 4. From this it is clear that at 250 m astern of the dredger the majority of suspended solids are not detectable within the water column above the 6% water depth ADCP^{TM} data corruption zone above the seabed.

Inspection of Figure 4 also shows that even the finest silt-sized particles largely disappear from the water column within a distance of 480 metres downstream of the dredger.

Returning to Figs. 2 and 3, it is clear that the acoustic backscatter results still indicate a significant plume of dispersing material beyond the 480 metres where the inorganic particulate load was considered to have reached background levels. This "plume" was detectable visually and by ADCP™ techniques for a distance of 3335 metres astern of the dredger. This was considered to be due to either aeration (considered unlikely at such distances), physico-chemical precipitates or entrainment of organic matter from the sediments when first reported by Hitchcock & Dearnaley (1994) and Hitchcock & Drucker (1996). The following section presents some estimates of the quantities of organic matter which could be attributable to benthic invertebrates fragmented by dredging within the dredged area.

Estimates of organic enrichment based on benthic biomass

There are relatively few studies where the biomass of benthic invertebrates has been quantified in sufficient detail to allow some estimates of the contribution which they might make to organic enrichment in the dredger outwash. Lees *et al* (1992) have reported that some components of the fauna in the outwash of the suction trailer dredger *Arco Tyne* appeared undamaged, but that worms and many crustaceans appeared susceptible to physical damage as a direct consequence of the dredging operation even if they were subsequently returned to the sea in the outwash. For the purposes of estimating the potential contribution represented by fragmentation of the benthos, it is probably realistic to use figures which are available for biomass reduction in dredged areas. These suggest a figure of some 70-90% reduction of biomass within the boundaries of dredged areas (for review see Newell *et al*, 1998).

Table 1 shows figures for the biomass of benthic macrofauna recorded from coastal sediments in U.K waters prior to dredging. Data are expressed as the maximum values recorded, the minimum values and the mean ash-free dry weight (AFDW) in g for up to 70 samples taken at 50 stations using a 0.2 m^2 Hamon grab. Data for the biomass have been calculated from the blotted wet weight using conversion factors in Eleftheriou & Basford (1989). Values for a site off Lowestoft, Norfolk have been recalculated from Kenny & Rees (1996), all other values are recorded in reports by Newell & Seiderer (1997a-d).

Inspection of Table 1 shows that the maximum biomass can be as high as 67.14 g AFDW and as low as 0.001 g AFDW per 0.2 m^2 Hamon grab sample, reflecting the high variability of benthic community composition in coastal sand and gravels deposits. The average maximum values for all survey areas was 40.06 g AFDW. The average of the minimum values was 0.0127 g AFDW and the mean for all 242 samples at all sites was 3.767 g AFDW per 0.2 m^2 Hamon grab sample.

These data allow some estimates to be made of the likely contribution which fragmented benthos could make to the organic content of outwash from a typical working dredger, assuming complete removal of the benthos along the path of the draghead from the dredger. Field records show that the mean volume of sediment from which the macrofauna was extracted was as follows: St Catherine's, Isle of Wight (not measured), Folkestone, Kent 11.790 litres (SD 5.30; N=133); Orford Ness, Suffolk 13.86 litres (SD 4.31; N=59); Lowestoft, Norfolk 15.13 litres (SD 5.28; N-57). The mean volume sampled per station for all survey areas was 13.6 litres. The specific gravity of the sediments is approximately 1.30, so the average weight of sediment from which the macrofauna was extracted was 17.67 kg. Multiplication by the total amount of sediment processed by a dredger during normal loading operations allows calculation of the biomass of organic matter associated with the dredged material.

TABLE 1

Biomass of benthic macrofauna recorded from coastal sediments in UK waters prior to dredging*

SITE	AFDW of Benthos (g per 0.2m^2)					SOURCE
	Max	**Min**	**Mean**	**S.D.**	**N**	
Lowestoft, Norfolk	-	-	4.4	-	-	Recalculated from Kenny & Rees (1996)
St. Catherine's Isle of Wight	48.45	0.03	5.59	8.97	52	Newell & Seiderer (1997a)
Folkestone, Kent	23.5	0.01	4.95	23.55	70	Newell & Seiderer (1997b)
Orford Ness, Suffolk	67.14	0.001	3.18	9.70	60	Newell & Seiderer (1997c)
Lowestoft, Norfolk	21.13	0.01	1.49	3.49	60	Newell & Seiderer (1997d)
MEAN	40.055	0.0127	3.767			
S.D.	21.881	0.0122	14.28			
N	4	4	242			

***** Data are expressed as the maximum values recorded, the minimum values and mean Ash-free Dry Weight (AFDW) in grams for up to 70 samples taken at 50 stations using a 0.2m^2 Hamon Crab which took an average sample of 23.1 kg sediment. Data for the biomass have been calculated from blotted wet weight using conversion factors from Eleftheriou & Basford (1989). The mean value for all stations has been calculated from the total data where N-242.

Table 2 shows the mass of organic matter (AFDW) estimated to be discharged from a typical marine aggregates dredger of 4,500 t hopper capacity based on the biomass of benthic invertebrates shown in Table 1, the tonnes of sediment processed during a normal loading operation and the volume of water discharged through spillways and screening. Calculations are based on an estimated 12,158 t of solids processed and a total water discharge of 34,866 t (Hitchcock & Drucker, 1996).

Inspection of Table 2 shows that relatively large quantities of organic matter could be derived from fragmentation of the benthos. During a normal loading of 4,500 t of cargo, a maximum of some 35.3 t AFDW of organic matter could be discharged in the 34,866 t of outwash from the dredger. A minimum of 0.0005 t AFDW and an average for all areas of 1.98 t AFDW organic matter discharged per cargo is indicated in Table 2. Since the volume of outwash is known, the concentration of organic matter can be calculated from the biomass data. This indicates that a maximum of 1,012.6 mg AFDW per litre could be derived from the benthic biomass recorded off Orford Ness, Suffolk, and a mean for all areas of 56.82 mg AFDW per litre in the outwash at the point of discharge.

TABLE 2

Mass of organic matter (AFDW) estimated to be discharged from a typical marine aggregates dredger of 4,500 t hopper capacity.*

SITE	AFDW of Organic Matter estimated to be derived from Benthos					
	Tonnes per Cargo			mg AFDW per litre		
	Max	Min	Mean	Max	Min	Mean
Lowestoft, Norfolk	-	-	2.3138	-	-	66.36
St Catherine's, Isle of Wight	25.4782	0.0158	2.9396	730.75	0.4525	84.31
Folkestone, Kent	12.3588	0.0053	2.6030	354.44	0.1508	74.66
Orford Ness, Suffolk	35.3066	0.0005	1.6723	1012.6	0.0151	47.96
Lowestoft, Norfolk	11.1115	0.0053	0.7835	318.7	0.1508	22.47
MEAN	21.63	0.0067	1.9809	604.13	0.1915	56.82
S.D.	11.51	0.0064	7.512	330.11	0.1845	215.44
N	4	4	242	4	4	242

*Estimates based on the biomass of benthic invertebrates shown in table 1, the tonnes of sediment processed during a normal loading operation (12,158 t) and the volume of water discharged through hopper spillways and screening chute (34,866 t). The mean value for all stations has been calculated from the total data where N-242.

Many of the fragmented marine invertebrates are likely to be rich in lipids, and may thus account not only for the "far field" scatter recorded by ADCP techniques but also the characteristic surface "slick" which can be seen well downstream of the point at which suspended inorganic particle load is indistinguishable from background levels. The following section presents the results of analysis of the outwash from an operational dredger to determine the concentration of organic and suspended solids load which occurs in the outwash of a dredger during normal loading operations.

Organic enrichment of spillway discharges

Table 3 shows the volume of water, dry weight of particulate matter (g) and ash-free dry weight (AFDW, g) of control seawater samples and a series of 20 spillway samples taken during normal loading operations by a modem suction trailer dredger of some 5,000 t hopper capacity. Data are for a cargo loaded off Southwold, Suffolk in April 1998. Values for the background inorganic and organic matter recorded from the control seawater samples have been subtracted in the final column to give concentration of sediment (g/l) and organic matter (AFDW mg/l) in water discharged from the dredger during the course of the loading operation. Samples 1-15 (inclusive) are for an unscreened "all-in" cargo. Samples 16-20 are for outwash from a cargo from which the fine sand component had been removed by screening and discharged through a separate reject chute.

TABLE 3

Volume of water, dry weight of particulate matter (g) and Ash-free Dry Weight (AFDW - g) of control seawater and a series of 20 samples of hopper overspill taken during normal loading operations by a modern suction trailer dredger of approx 5,000 t hopper capacity. *

						Overspill composition	
Sample #	**Reference #**	**Volume of Water (ml)**	**Dry Weight (g)**	**Weight after combustion (g)**	**Difference (g)**	**Sediment ($g.l^{-1}$)**	**Organic Matter ($mg.l^{-1}$)**
Control		620	0.4782	0.3196	0.1586	-	-
1	53	790	4.2665	3.9873	0.2792	4.5322	97
2	56	770	6.1127	5.6126	0.5001	6.7736	393
3	59	830	8.1938	7.5065	0.6873	8.5284	572
4	62	800	8.7111	6.2725	2.4386	7.3251	2792
5	65	730	11.599	8.0563	3.5433	10.5205	4854
6	68	640	6.6583	6.2726	0.3857	9.2854	347
7	71	850	10.221	9.4816	0.7397	10.6393	614
8	74	610	10.978	10.1562	0.8218	16.1340	1091
9	79	810	5.9273	5.4039	0.5234	6.156	390
10	82	770	8.3737	7.7814	0.5923	9.5902	513
11	85	900	5.1144	4.9859	0.1285	5.0245	-
12	88	830	16.315	15.5592	0.7561	18.2305	655
13	91	770	12.969	12.1248	0.8444	15.2310	841
14	94	810	11.751	10.6112	1.1398	12.5847	1151
15	97	710	11.251	10.2055	1.0461	13.8584	1217
16	105	840	6.3182	5.6749	0.6433	6.2403	510
17	115	720	18.570	14.2991	4.2711	19.3445	5676
18	120	1070	17.193	15.5822	1.6115	14.0473	1250
19	130	1000	7.7477	7.2049	0.5428	6.6894	287
20	135	580	32.913	30.2219	2.6914	51.5912	4384
MEAN		791.5	11.059	9.8500	1.2093	12.6163	1454.4
S.D.		116.9	6.5312	5.9167	1.1364	10.1736	1683.9

*Data are for a cargo loaded off Southwold, Suffolk in April 1998. Values for the background inorganic and organic matter recorded from the control sample have been subtracted in the final columns to give sediment concentration ($g\ l^{-1}$) and organic matter (AFDW $mg\ l^{-1}$) in the water discharged from the dredger during the course of the loading operation. Samples 53-97 (incl.) are for an unscreened "all-in" cargo. Samples 105-135 are for outwash from a cargo from which the fine sand component had been removed by screening and discharged through a separate reject chute.

Inspection of Table 3 shows that the outwash recorded from the dredger working in hitherto unexploited deposits off Southwold, Suffolk comprised approximately 12.6 g/l of suspended solids and as much as 1454.4 mg/l AFDW of organic matter. This is more than the highest value of 1012.6 mg/l AFDW calculated to be available from the macrofauna reported by Newell & Seiderer (1997c) for the Shipwash Gabbard area off Orford Ness, Suffolk (see Table 2) and may reflect locally rich benthic resources in the dredged deposits off Southwold.

Table 4

Lipid content of a sample of seawater and a series of 20 samples of hopper outwash taken during normal loading operations by a modem suction trailer dredger of approx. 5,000 t hopper capacity.*

Sample #	Reference #	Lipid Concentration (mg. l^{-1})	
		In Sample	**In Overspill**
Control 1		0.12	-
1	53	0.70	0.58
2	56	0.31	0.19
3	59	50.66	50.54
4	62	0.16	0.04
5	65	0.57	0.45
6	68	26.32	26.20
7	71	.43	0.31
8	74	0.24	0.12
9	82	0.30	0.18
10	85	0.39	0.27
11	88	0.36	0.24
12	91	45.01	44.89
13	94	4.15	4.03
14	97	0.59	0.47
15	105	3.30	3.18
16	110	5.82	5.70
17	115	0.53	0.41
18	120	0.59	0.47
19	130	0.36	0.24
20	135	0.43	0.31
MEAN	-	-	6.941
S.D.	-	-	15.135

*Data are for a cargo loaded off Southwold, Suffolk, in April 1998. Values for the background lipid recorded from the control seawater sample have been subtracted in the final column to give the lipid concentration (mg.l^{-1}) in the water discharged from the dredger during the course of the loading operation.

It is clearly of interest to determine whether the lipid content of the organic matter recorded in the outwash is sufficiently high to account for the characteristic surface "sheen" observed in the far field of dispersing outwash plumes downstream from dredging operations. Table 4 summarises the lipid content of a sample of sea water and a series of 20 samples of hopper outwash taken during the loading operation off Southwold, Suffolk in April 1998. Values for the background lipid recorded from the control sea water sample have been subtracted in the final column to give the lipid (mg/l) in the water discharged from the dredger during the course of the loading operation. Inspection of Table 4 shows that the lipid content of the outwash samples was highly variable, probably reflecting the type of fragmented invertebrate material discharged at the time the samples were taken. Values as high as 50 mg/l were recorded, the average for the series of 20 samples being 6.94 mg/l. Based on this average value, the lipids represent 0.48% of the 1454.4 mg/l organic matter discharged.

It is now possible to summarise the mass discharges and concentrations of materials from a suction trailer dredger of 5,000 t hopper capacity loading a cargo off Southwold, Suffolk in April 1998. The volume of water discharged is based on the difference between the pumping rate of 7750 m^3 and 5.5 h loading time recorded during the survey, and an average value of 14,073 t recorded for solids pumped during loading. The results are summarised in Table 5.

This shows that a total of 28,552 t of water were discharged by the dredger during the loading period of 5.5 h off Southwold, Suffolk in April 1998. For a cargo of 5,630 t, it was estimated that 8,713 t of material were rejected via the screening chute and 360 t through outwash from the hopper spillways. Organic matter measured in the outwash and assumed to apply to the entire water discharge from both screening chute and hopper outwash was as much as 41.5 t comprising 0.20 t of lipids. The corresponding concentrations recorded in the outwash of the dredger were 12.6 g/l of sediment, 1.45 g AFDW of organic matter and 0.007 g/l of lipids. The values for sediment in the outwash are rather lower than the 750 t cited by Hitchcock & Drucker (1996) and may reflect the fact that (a) their original study was for worked deposits on the Owers Bank whereas the outwash data recorded here was for a hitherto unexploited area with a lower proportion of fine material, and (b) the technique of loading differed considerably between the two dredgers (central loading chute in 1996 as opposed to two variable loading towers in 1998).

Table 5

Mass discharges and concentration of materials from a suction trailer dredger of 5,000 t hopper capacity loading a cargo off Southwold, Suffolk, in April 1998.*

	Total Tonnes discharged per cargo	**Concentration measured in outwash ($g.l^{-1}$)**
Water	28,552	-
Sediment in hopper outwash	360	12.608
Sediment rejected by screening	8,713	-
Organic matter (AFDW)	41.5	1.454
Lipids	0.20	0.007

*Volume of water discharged is baaed on the difference between a pumping rate of 7,750 m^3 h^{-1} and 5.5 h loading time recorded during the survey, and an average value of 14,073 t for solids pumped during loading. Values for sediment in the screening reject chute have been estimated from the cargo loaded and pumped solids.

Conclusions

The values cited here are the first direct measurements of the concentration of organic matter in the outwash from a marine aggregates dredger, and are based on a cargo loaded from a hitherto largely unexploited site to the east of Southwold, Suffolk. The values therefore probably represent maximal concentrations for coastal deposits and are likely to be less than this in heavily-exploited areas where the biomass of benthic invertebrates has been reduced within the dredged area.

Clearly, the discharge of as much as 1.45 g/l AFDW of organic matter of outwash from the dredger during loading operations in areas where the benthic fauna is rich is sufficient to account for the presence of a detectable "plume" beyond the point at which inorganic suspended solids have fallen to background levels. The fact that significant quantities of lipids are associated with this material may reduce the rate of sedimentation of fragmented material and account for the commonly observed surface "sheen" at the extremity of the dispersing plume.

It is of interest to compare the organic input from dredged material described above with that from a typical detrital-based ecosystem. Kelp bed seawater in the Southern Benguela upwelling ecosystem near Cape Town, South Africa, contains 300-400 µg/l carbon and 46-71 µg/l nitrogen (Seiderer & Newell, 1985). Mann (1982) gives the following ratio for AFDW to carbon: 1 gram Carbon = 2.6 g AFDW organic matter. The detrital load in the seawater of kelp beds is therefore 0.780- 1.04 mg/l. By comparison, the organic loads discharged from the dredging operation recorded above are 1.45 g/l. That is, about 1000 times the organic content of some of the richest detrital ecosystems in the world. Even allowing for the dispersion which must occur downstream from the dredger, it seems likely that the organic matter derived from fragmented invertebrates in the dredger outwash is sufficient to account for the enhanced species diversity and biomass of benthic invertebrates beyond the boundaries of dredged areas reported by others (see Poiner & Kennedy, 1984).

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