7.0 DISCUSSION

The terms of reference for this study were, overall, to undertake an integrated physical and biological assessment of the seabed resources as may be impacted by marine aggregates dredging. These objectives have been met. In the early stages of the project, following the analysis of the first set of biological grabs, the resources of the project allocated to physical investigation of the seabed by more extensive underwater video and diver investigation were re-allocated to extending the scope of the biological studies. In particular, this was to identify the very near-field effects and, unexpectedly, to make first approximations to rates of recovery of biological resources that was originally not included within the work-scope.

We have demonstrated that ADCP techniques supported by traditional water sample characterisation still provide a best value approach to defining the gross morphology of the dispersing plume. New developments in data manipulation and image processing have enabled us to re-process datasets we collected for earlier studies (Hitchcock *et al*., 1998) and find new components and sub-divisions. Specifically, the extension to the near-bed sediment plume at the benthic boundary that is seen to persist beyond the limits of past surveys is important and should be considered in great detail. This is especially so in light of the trend towards offshore resources where water depths are deeper and sediments may have the propensity to travel further before deposition.

7.1 Physical Effects of Dredging

We have shown that a small-scale operation of some 150,000 tonnes per annum, even with intensive extraction rates per km^2, has a limited impact on the environment. The evidence suggests that, other than where sediments are physically disturbed by removal, physical resources are largely unaffected. There is some minor change in sediment characteristics. Benthic biological resources would appear to be able to cope with the stresses induced by the minor change in sediment type, and indeed appear to benefit by the increased food resource provided by disturbance of the sediments.

What is now apparent with the development of image analysis techniques is that with the development of an extension to the nearbed benthic boundary, the sediment plume provides a mechanism for potential extension of the impact beyond the zone of extraction. This effect, apparently not significant on the North Nab 122/3 site, is expected to be significant for those areas where screening of cargoes takes place. More importantly, this may hold especially true for those deeper water communities (40 metres or so), less exposed to and tolerant of natural disturbances to the sedimentary regime.

It is stressed that scaling up of the results recorded so far from the comparatively shallow water small scale operations to deeper water and more extensive operations with screening of cargoes is not a realistic option. Fundamental data collection at these deep-water sites is required to understand the response signatures of the benthic communities to disturbances, both natural and anthropogenic, and the extent of plume migration under the different phases of development and dispersion.

7.2 Biological Effects of Dredging

The results that have been cited above for the North Nab survey area show that the data for particle size composition of the sediments fall into well-defined groups that show a high level of internal similarity between stations in any one Group. In contrast, whilst the data for samples of macrobenthos also fall into well defined Groups or communities, there is considerable sample-to-sample variability in species numbers (*S*), population density (*N*) and biomass (*B*) (see Text Table 6.1.2a). Similar results have been obtained for gravel and sand deposits off Hastings, Kent by Kenny (1998), off Orford Ness, Suffolk (Seiderer and Newell, 1999) and off Folkestone, Kent (Newell *et al*. 2001).

A probable explanation for the clear separation of the macrofaunal groups that occurs despite the variability of the samples used in the multivariate analysis of community composition is that there is a high degree of “redundancy” in the species that characterise community composition (Clarke and Warwick, 1998). Gray *et al*. (1988) showed, for example, that ordinations for macrobenthic community structure at six stations in Frierfjord, Norway, were similar to the results for the entire species complement even when only 20% of the species, selected at random, were used in the analyses.

Warwick (1993) subsequently showed that analysis at taxonomic levels higher than that of species shows similar patterns to the full species analysis. The fact that there is a high degree of variability between the single samples taken at each of the survey stations is therefore unlikely to affect interpretation of the results of multivariate analysis community composition in the survey area adjacent to North Nab Production Licence Area 122/3. Each of the single samples taken evidently contains sufficient taxa to define the community from which the sample was taken, despite the under-sampling incurred by use of a 0.2 m² Hamon grab in the complex communities of macrobenthos that occur in coastal gravel deposits (*see also* Whitlatch, 1981; Morse *et al*., 1985; Parry *et al*., 1999)

The variability between samples of macrobenthos obtained with a 0.2 m² Hamon grab has important implications, however, for marine environmental monitoring programs that depend on univariate analysis of species diversity, population density or biomass of the macrofauna for an assessment of the impact of environmental variables, including disturbance by man, on benthic biological resources. A high diversity of species that are uniformly represented in the population evidently leads to serious under-sampling of the macrofauna by conventional methods such as the 0.2 m² Hamon grab commonly used in benthic surveys of sands and gravels. Estimates of species numbers, population density, biomass and indices that depend directly on these are likely to be heavily dependent on the number of replicate samples taken, the type of deposit, the number of taxa present the distribution of species within the population and probably the size of grab sample taken (see also Warwick and Clarke, 1995; 1996).

The conclusion from our survey of the macrobenthos of sands and gravels in the North Nab survey area is that multivariate analyses of community composition are evidently robust, and give a clear separation of faunal groups based on single samples, despite variability in the data between stations in the survey area. However, as many as 10-13 replicate samples are evidently required for assessment of indices that depend on species composition and distribution of species within the macrobenthic population. Conventional 0.2 m² Hamon grab samples are commonly used to obtain data on species variety (*S*), population density (*N*) and biomass (*B*) for analysis of community composition. The results show that at least 3 replicate samples are required to obtain a satisfactory assessment of the species composition of the macrobenthos of sands and muds, but 10 or more replicates are required for gravels.

7.3 Synthesis: Implications for Management

Efforts to define impact generally concentrate on the biological resources. Within this project, significant progress has been made into defining these biological components from first principles. Re-allocation of funds from the physical investigations originally proposed reflects the importance associated with these aspects. The findings of this project may be used to refine best practice procedures for conducting benthic studies at aggregate sites, a number of which have recently been produced (*see*, for example, John *et al*, 2000 and Boyd *et al*, 2002).

Impacts due to marine aggregate mining in small intensively dredged sites such as the study area North Nab 122/3, which are subject to reasonable natural disturbance, appear to be relatively localised and minor. Natural disturbances prior to dredging operations have encouraged development of adaptive communities suitable for such environments, and appear capable of dealing with and recovering from stresses caused by the dredging activities within reasonable time spans.

Physical effects from the non-screening operation are largely confined to the physical actions of the draghead on the seabed. Sidescan sonar and high-resolution bathymetry provide robust evidence of disturbances. Persistence of disturbances and recovery of the seabed to pre-dredge conditions has not been possible to determine within the timescale of the project, without abandoning an area of the production licence. However, the lack of evidence of physical impacts beyond the dredge activity is in itself proof of the small potential for cumulative impacts with other dredging operations nearby.

Sites which have been left undredged for known times suggests that initial recolonisation by mobile components of the benthos can occur within weeks with some 70-80% of the species variety returning. Restoration of biomass is achieved by growth of the small individuals that recolonise the deposits.

This stage is incomplete even after 18 months compared with areas some distance away from the dredge site, and this finding is in keeping with anecdotal information available from the literature. The results for trailer-dredged studies elsewhere indicate that species diversity may initially recover much quicker. Population density is not dissimilar to anchor dredge sites, with biomass recovering to within 80% of the undredged sites within 3 months.

We conclude with the following general hypothesis based on this study and another partial study carried out in the Southern North Sea (Newell *et al*, 2002) on a trailer dredge study site:-

(1) The degree of suppression of the fauna in the dredge site itself is clearly dependent on the intensity of dredging. In high intensity dredging (North Nab) the suppression of population density, species variety and biomass can be as high as 60-80%. In areas that are dredged less intensively by trailer techniques, the suppression is either less than at anchor dredge areas (North Nab), or undetectable (North Sea).

(2) There is no evidence of an impact outside the immediate dredge sites.

(3) Both sites show some evidence of an enhanced biomass and population density at some distance from the dredge site, possibly reflecting the deposition of organic components from fragmented invertebrates discharged in the outwash.

(4) Recovery of population density and species variety can be very rapid indeed. This depends on the degree of disturbance to which the area is subjected under natural conditions. In shallow water wave disturbed areas such as the North Sea, colonising species are mobile and well adapted to rapid recolonisation. In more stable (equilibrium) communities such as occur on coarse rocks and cobbles, recolonisation is slower.

(5) Recovery of biomass is achieved by growth of the recolonising individuals. In this case restoration of biomass generally requires at least several years. In some of the deeper water communities that we have recently analysed, individual species may be at least 20 years old. This implies that deep-water stable equilibrium communities may require a time of at least 20 years for recovery, compared with 2-3 years in shallow water coastal sands.

(6) Anchor dredging has a significant impact on the species variety, population density and biomass of benthic macrofauna, although without screening is largely limited to within a hundred metres of the active dredged zone. Trailer dredging, on the other hand, appears to have a much lesser impact on species variety, population density and biomass, although this may be limited to the lower intensity of trailer dredging activities in the study areas. However, species recovery data suggests that recovery is quicker for trailer dredge areas, due to the reduced distance of 'inwalk' for colonising species (only the widths of trailer tracks), compared with the larger total destruction of an anchor dredged area.

(7) On the available evidence collected herein, we would suggest that trailer dredging over a wide area at an intensity carefully matched to the potential times for species recovery (indicated by the response times to natural disturbances e.g. turbulent shallow water or less disturbed deeper waters) will be more sustainable than intensively dredging small areas of seabed.

Survey protocol must take notice of the implications of grab sample size and sediment type. In the case of sands and muds that are dominated by one or a few taxa, only 0.4-0.6 m^2 of seabed (i.e. 2-3 replicate samples with a 0.2 m^2 Standard Hamon Grab) are required to discover at least 80% of the species present in the deposits, even when s many as 82 taxa are present. Where deposits comprise a larger species variety such as in coarse gravel samples, a area of seabed of up to 2.0 m^2 (i.e. 10 replicates of a 0.2 m^2 grab) are required to define 80% of the species present. Finally, we have shown that in coarse gravels found at North Nab, an area of seabed of at least 2.6 m^2 (i.e. 13 replicate samples of a 0.2 m^2 grab) are required.

The project has indicated that the effects of dredging in deeper waters and those less disturbed by natural events, and specifically those sites where screening takes place, may be more susceptible to impact and less capable of quick recovery. The near bed extension to the plume that has been proven in both this study, reprocessing the data of our previous work (Hitchcock *et al*., 1998) and work in the southern North Sea (Dickson and Rees, 1998) provides an important mechanism for potential extension of impacts beyond the boundaries discovered so far. Investigation of these 'far field' effects integrating monitoring of the near bed plume extension is clearly required.

The results of this study and a recent study at Area 408 in the southern North Sea (Newell *et al*, 2002) show that the rate of recolonisation by mobile 'opportunistic' species characteristic of disturbed sands and gravels can be sufficiently rapid to be in equilibrium with the rate of loss by trailer dredging at small scales. However, restoration by growth of the colonising individuals takes longer, and at Area 408 would appear to be largely complete within 12 months. Moreover, these results should not be applied uncritically to other areas. At higher levels of exploitation, for example, it is probable that the rate of removal of macrofauna by dredging may exceed the rate of recolonisation, even in high-energy sites.

Where deposits are stable, as in low energy coastal or deep-water sites, or where deposits are coarse, the biological community is represented by long-lived and slow growing components that have a slow rate of reproduction. These '*k*-strategists' or 'equilibrium species' may take longer to recover both species variety and population density and for the biomass to be restored by growth of the individuals.

Importantly, the detailed analyses of these and other data for this project has revealed the susceptibility of analysis methods to 'noise' within the datasets. This is caused by inter-sample variability due to significant under sampling of the diverse benthic macrofauna of sands and gravels by conventional methods. We have shown that single samples of macrofauna obtained from a 'Hamon' type grab contain sufficient taxa to use non-parametric multivariate analytical techniques to define community composition. Values for individual variables, such as species variety are, however, heavily dependent on the number of replicate samples taken. At least 3 replicate samples are required to obtain a satisfactory assessment of the species composition of the macrobenthos of sands and muds, but that 13 or more replicates are required for gravels. The repercussions of this in terms of scale, frequency, density of sampling sites and number of replicate samples and subsequent cost implications must be carefully considered when designing suitable monitoring protocols.

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