

Introduction

Coastal marine sediments carry out important 'ecosystem functions' including the biogeochemical cycling of carbon, nitrogen, phosphorus, the storage of contaminants and providing a resting place for algal cysts. Disturbance of the sediments via natural or anthropogenic impacts can lead to undesirable consequences such as the impairment of biogeochemical function, increased bio-availability of contaminants and the wider distribution of algal toxicity problems (Figure 1).

Human activities such as fishing, dredging and dredge material disposal, construction and sand and gravel extraction can have a deleterious impact on the quality and function of marine and estuarine ecosystems. These activities are subject to regulation in respect of their physical and macro-biological environmental impact, but the consequences for sediment function are not considered.

CEFA is currently conducting a four year project (04/01 to 03/05), funded by DEFRA, to assess the significance of the wider impacts of seabed disturbance taking account of the relative magnitude (space and time) of both natural (i.e. storms and tides) and anthropogenic activities. The overall aim is to provide a regional-scale assessment, using a combined GIS (Geographical Information System) and modelling approach. It is intended that this new understanding will assist in the development of a management tool to support specific assessments of disturbance on environmental quality.

Two field surveys have now been undertaken (October 2001 and July 2002). These targeted several impact areas with the main aim of looking at response of sediment biogeochemical processes and benthic epi- and infauna assemblages across disturbance gradients (trawling, dredge material disposal, natural). Preliminary results looking mainly at the impact of trawling are presented here.

Trawling:

Trawling can impact the seabed directly via scraping and ploughing of the substrate, sediment resuspension, destruction of the benthos and dumping of processing waste (Jones, 1992). Indirect effects include post-fishing mortality of target and non-target species, and long-term trawl induced changes to the benthos. All these impacts may have significant effects on sediment biogeochemistry (Parker *et al.*, 1999). The main issues that this project has been addressing with respect to trawling impact are:

Impact on sediment functioning

- changes in carbon input and mixing of organic matter to depth (bioturbation or physical mixing)
- changes in sediment cycling of carbon and nutrients and resulting end-products (redox changes, aerobic vs. anaerobic remineralisation, NH₄⁺ to NO₃⁻ partitioning, denitrification, sulphate reduction stimulation)
- sediment nutrient release to the water column (interface fluxes and resuspension)
- changes in substrate (particle size spectrum)

Linkage of benthic community impact with biogeochemistry

- changes in size structure and community
- changes in sediment structuring and bioturbation (C mixing and oxidation, nutrient fluxes)

Spatial extent vs. intensity vs frequency of disturbance

Trawling and other impacts in the context of natural disturbance and ecological sensitivity

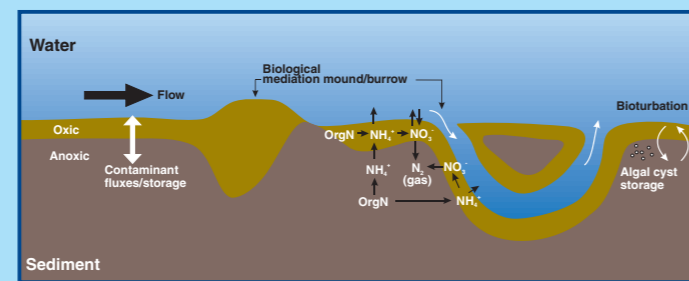


Figure 1: Conceptual diagram of undisturbed sediment cycling of carbon + nutrients, storage of contaminants + algal cysts

Methods:

At each site within an area the following measurements were taken;

- Side-scan sonar of sampling site to look at bedforms and signs of trawling impact.
- Epi- and In-fauna (2m Jennings beam and Hamon grab).
- Oxygen profiles in cores with microelectrodes (OX-500µm, Unisense)
- Nutrient fluxes from core incubations and pore-water nutrient profiles
- Denitrification (stable isotope ¹⁵N technique)
- Sulphate reduction (5 depth measurements, turnover of a radio-labelled ³⁵S tracer)
- Oxygen uptake
- Sediment properties (porosity, sediment chlorophyll (labile C), total organic carbon, particle size analysis)
- Water column characteristics (CTD, nutrients, DO, SPM, chlorophyll).

Results:

The bulk of the results presented here are from the October cruise (winter scenario) but some side-scan sonar data of the sites from the July cruise are also presented.

Acoustics:

Figures 5 and 6 show examples of side-scan sonar images used to look at bedforms, or for presence of trawl scars, at high and low impact sites prior to sampling. Figure 5 shows evidence of sand waves towards the top and a more homogenous seabed surface to the bottom in the Thames. Figure 6 shows a clear image of a double trawl scar at Outer Silver Pit. The presence or absence of trawl scars can give indication of impact but longevity of trawl scars can be a function of sediment type and natural physical disturbance. For example: trawl scars were rarely seen at high impact sites in the Thames which has high natural tidal bed stresses.

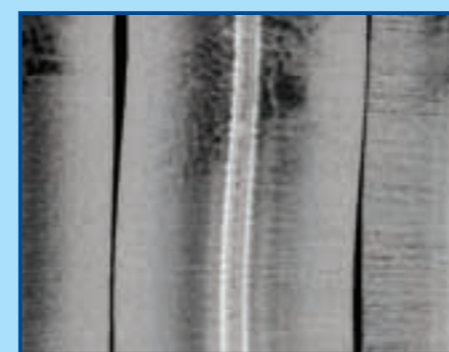


Figure 5: Thames site side-scan image

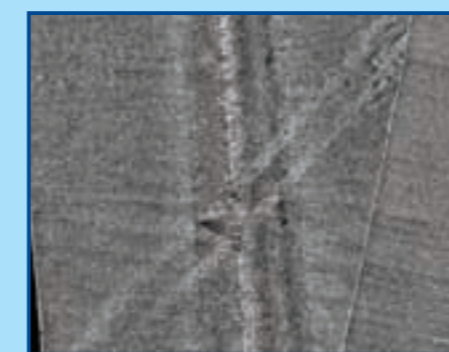


Figure 6: Outer Silver Pit side-scan image

Faunal analysis

Epifauna

In the MDS plot Figure 7 shows analysis of epifaunal information from the October cruise (including the Tyne dredge disposal site) each labelled point represents an epifaunal sample. The closer the points, the more similar the samples are in terms of their species abundance (using the Bray-Curtis similarity index).

There is a clear separation between the replicates from the two sites in the Outer Silver Pit, those from the high impact site have been ringed in red and those from the low impact site ringed in blue.

The four sites in the Tyne have split into two groups, one consisting of the two low impact sites and the other of the two high impact sites. The other point of interest in relation to the Tyne sites is the tighter clustering of the low impact samples in comparison to the high impact samples. This wider spread in the high impact samples is due to greater variability between the replicates. Disturbance such as commercial trawling or natural disturbance may be expected to result in a more "patchy" environment and hence greater variability between samples from that area.

The Thames is naturally very variable perhaps due to high natural disturbance and this may be the reason for the lack of separation between the high and low human-impact sites in that area. The variability both between and within sites is high in the Thames suggesting patchiness on a relatively small scale.

Infauna:

Infauna from Hamon grabs have been identified to species (apart from polychaetes to family) and also weighed for size analysis (fishing impact studies by Jennings *et al.* 2001 have shown that this disturbance tends to leads to shifts in the size spectrum towards smaller sizes). Figure 8 shows the number of infaunal species found at each site. It is clear the three areas have different species numbers with the Thames sites having lowest diversity (perhaps linked to high natural disturbance) but there is no consistent difference between high and low impacted sites. Generally, infaunal species diversity is similar within a site and has more variance between areas.

This form of analysis for epi- and in-fauna does not take into account the functional role that each organism plays in the environment. The next step in the analysis of this data is to normalise for environmental variables (e.g. depth, PSA) and apply a bioturbation index to each species in order to quantify the level of bioturbation at each site.

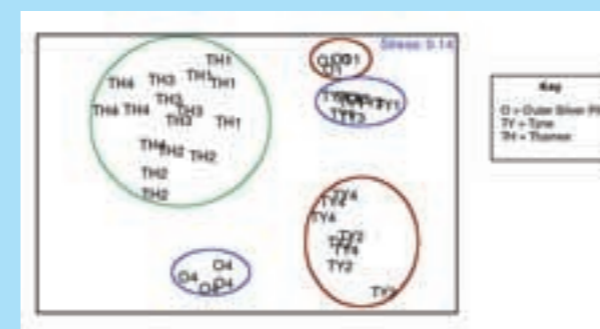


Figure 7: Multidimensional Scaling (MDS) plot of Bray-Curtis similarity for all samples, colonial species removed, data standardised and square root transformed

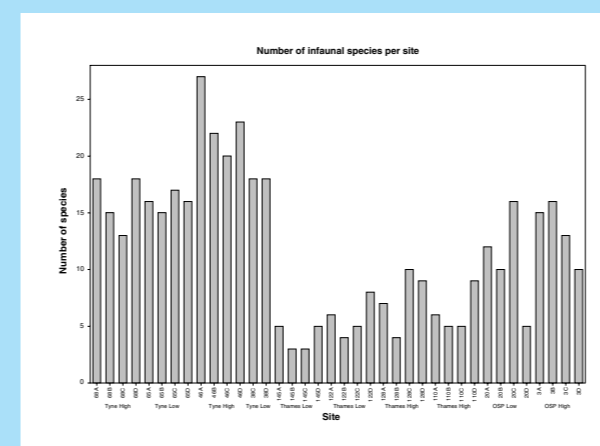


Figure 8: Number of infaunal species per site at the 3 main areas

Sediment biogeochemistry and process rate measurements:

Oxygen

Selected data from all 3 areas is presented in Figure 9. The OSP high-impacted cores had deeper oxygen penetration than low-impacted sites (i.e. more gradual decrease in oxygen with depth) and also more variability than the low-impacted sites. The Tyne sites were more consistent (i.e. less variability over the 2 types of site although perhaps the high-impacted sites were more variable).

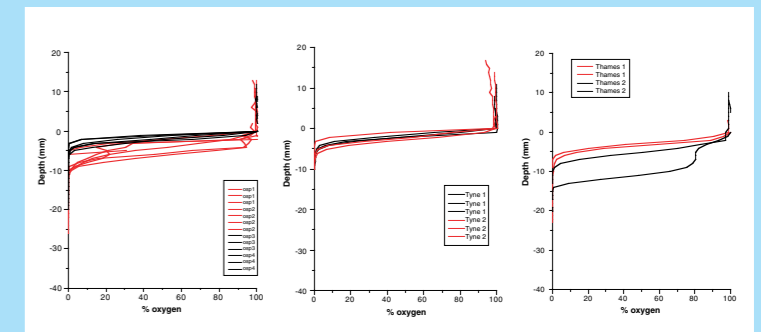


Figure 9: Oxygen profiles from impacted (red) and non-impacted sites (black) at Outer Silver Pit (OSP), the Tyne and the Thames Embayment.

Oxygen penetration in the Thames sites was deeper and showed much higher variability. Flux rates and resolution sensitivity calculations will be conducted on these, and July cruise data in the future.

Denitrification, sulphate reduction and oxygen uptake

Preliminary analysis of sediment process measurements (oxygen uptake, denitrification and sulphate reduction) in Figure 10 suggest little impact of physical disturbance on sedimentary biogeochemical function at any of the three locations. Data for the Thames sites suggest that there is as much variation amongst sites that are naturally exposed to high degrees of physical disturbance compared to those which are or are not subjected to the physical impacts of beam trawling such as the Outer Silver Pit. However, some of the rate measurements (for example oxygen uptake) were near the limit of detection which may hide any changes. The Tyne site had a high organic C content and high sulphate reduction levels but the high hydrocarbon content of the sediment may not be as bioavailable as other forms of C.

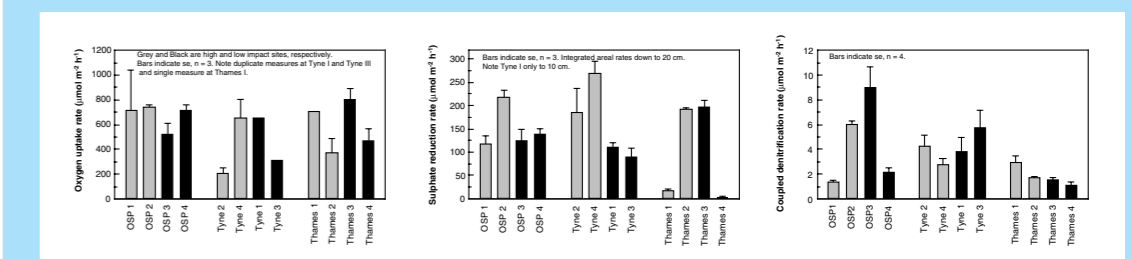


Figure 10: Oxygen uptake, sulphate reduction and coupled denitrification rates measured at the three main survey areas (October 2001)

Conclusions and future

- Various disturbances impact the benthos and benthic interface. The extent and intensity of disturbances and impacts need to be rationalised on appropriate time and spatial scales.
- Results from the oxygen profiles, acoustic data and benthos information from the October cruise indicate some effects of disturbance. But the biogeochemical results suggest little impact of physical disturbance on sedimentary biogeochemical function at any of the three locations apart from perhaps increasing variability. Results from the July cruise may clarify these findings.
- The infauna and epifaunal information will be closely linked to geochemical findings via a bioturbation/benthic disturbance index which will be developed in the future. Aside from the species composition and size distribution analysis, species/family specific life history traits and mixing coefficient or bioturbation depth information will be incorporated which will link better to sediment geochemistry changes. This will give information on the geochemical role/function of the organisms rather than just their presence/absence and abundance.
- The regional function of coarse sediments (sands and gravels) needs to be integrated into this approach but is a challenge due to sampling limitations (SCOR, 2002)
- In the future *in-situ* measurement techniques including lander applications will be utilised to tackle some of these problems.

Acknowledgement

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References

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Site selection:

As most of the Southern North Sea has been impacted at some time by trawling (Jennings and Kaiser, 1998) finding a true control site was difficult. A trawling gradient approach was taken to compare areas of higher and lower trawling impact. Two contrasting areas at the Thames and Outer Silver Pit (OSP) were selected using a combination of historical overflight and more recent satellite information on fishing vessel distributions and fishing effort (Figure 2a + b). Both had good gradients (at least over an order of magnitude) of trawling intensity and similar sediment types but had differing regimes of natural disturbance as determined from bed stresses and tidal current ellipses from model predicted M2 tides (Figure 3).

Figure 2b shows the winter sampling sites within the 2 trawling impact areas. Four sites were measured in the winter cruise at both sites and in the summer 2 more sites in each area were added. On the winter cruise a dredge disposal site at the Tyne was also visited. Samples there were taken at sites selected on and off the dump site. The site positions are displayed in Figure 4, which is an acoustic survey of this site to help delimit the extent of the dredge disposal disturbance, which can lie outside the licensed area.

Figure 3: a) Model output of M2 tidal stresses for the North Sea. b) Predicted tidal current ellipses (u and v are east and north velocities)

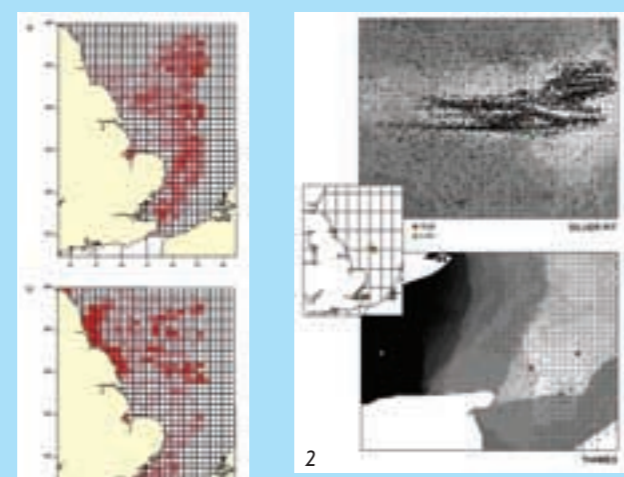
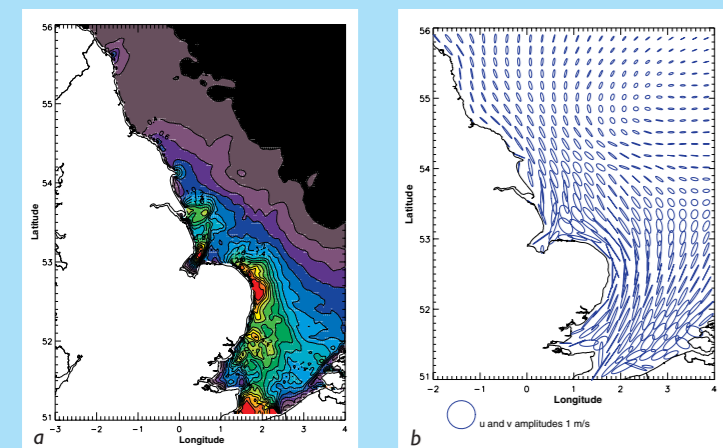


Figure 2: Trawling data 1) Intensity maps of mean a) beam trawler and b) otter trawler effort from 1998 and 1999 overflight data 2) Composite intensity maps (satellite and overflight information) for the two main survey areas (insert is the location of all 3 areas sampled on the winter cruise)

Figure 4: Tyne disposal area site locations

