

# Development of an integrated indicator of sediment carbon cycling – redox and bioturbation?

## Introduction

- There is a need for indicators of ecosystem health to support various European legislative and policy frameworks in relation to the management of human activities.
  - A key focus of the European Marine Strategy Directive (2007) is maintenance of ecosystem biodiversity, goods and services and focus on structure & function.
  - This includes development of indicators of seabed integrity.
  - Sediment functions can include carbon and nutrient cycling, role of organisms in controlling redox, bioturbation
- Challenge = linking site-specific observations of biogeochemical rates to regional scale approaches for indicator monitoring and management.

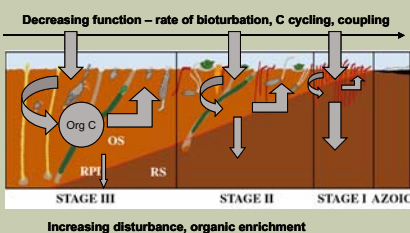
## Regional indicator development

Two candidate functional indicators relevant to carbon and nutrient cycling:

- a) an indicator of Community Bioturbation Potential (BPC)
- b) an indicator of sediment redox (aRPD - apparent Redox Potential Discontinuity as derived from Sediment Profile Images (SPI).

Testing the performance of these candidate indicators with respect to

- temporal and spatial variability
- response to human impacts (disposal sites, trawling)



The combined indicator uses both metrics to describe the condition of a site on the conceptual model in Figure 1. The BPC describes the benthic faunal function (in terms of bioturbation) and the aRPD describes the key sediment redox state and boundary between faster and slower carbon recycling (nitrate/sulphate).

Figure 1. Conceptual model (adapted from Pearson and Rosenberg, 1978) of benthic fauna and sediment redox changes along a gradient. The arrow sizes describe the predicted rates and significance of remineralisation routes

## Community Bioturbation Potential (BPCs)

- Reclassifies benthic assemblage into a functional 'bioturbation metric' with closer links to a carbon and nutrient cycling function (Solan *et al.*, 2004).
  - Derived from existing faunal datasets (species, biomass and abundance)
- $$BP = \sum(B_i/A_i)^{0.5} \times M_i \times R_i$$
- Includes biomass, abundance and also scores related to assessment of mobility (M) and reworking (R) for each species population.
  - The scoring for each species population (BP<sub>p</sub>) are combined to give a community bioturbation potential for each site assemblage (BPC).
  - BPC has been calculated for a range of datasets to give an idea of spatial variability and impact changes – Figure 2.
  - There is sufficient resolution in the metric to detect changes both by region (from baseline) and temporally (either inter and intra annual variability), Figure 3.
  - BPC is also capable of indicating disturbance by organic enrichment or disposal.
  - BPC also picks up changes in key bioturbator species such as *Amphipura*.

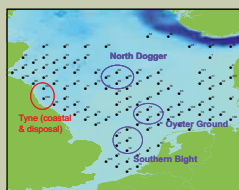


Figure 2. Datasets used for assessment and testing of BPC or aRPD metrics

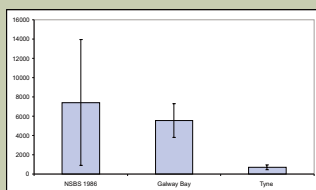


Figure 3. BPC variance across the NSBS, Galway and Tyne datasets

## Sediment redox - aRPD



Figure 4. Cefas Sediment Profile Imagery (SPI) camera

- aRPD derived from SPI images collected at various coastal and shelf sites in the North Sea.
- Figure 5a and b illustrate the deepening of the aRPD offshore and the associated example SPI images.
- Illustrates the scales in aRPD variability from 1 to 10cm and also the difference between impacted (disposal, trawling) and reference sites.

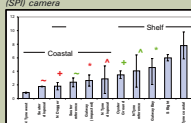


Figure 5a: Plot of aRPD for coastal and shelf sites. Green and red symbols illustrate reference and impacted sites respectively



Figure 5b: Example coastal and shelf SPI images

## Combined metrics

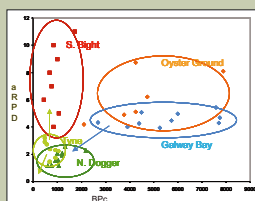


Figure 6. aRPD/BPC plots for coastal and shelf regions - references Arrows illustrate the changed location of sites given impacts due to organic enrichment, disposal or clean sand addition by capping.

- For sites where co-located fauna and SPI data exists, baseline aRPD and BPC characteristics of regions have been plotted as labelled in Figure 6.
- Illustrates the consistently low BPCs of the Southern Bight as expected from a site which is highly advective with mobile sediments.
- Locations could be used in future as a basis to detect temporal or impact driven changes.

## Regional carbon coupling

- Investigation of the regional variability of the BPC and relationship to other environmental variables (carbon, sediment type, depth).
- PCA analysis of 1986 North Sea Benthos Survey data - Figure 7
- North sea sites show a continuum
- Main North Sea ecohydrodynamic/coupling regions can be mapped into PCA sectors.

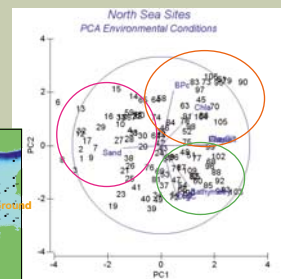


Figure 7. Regional PCA of BPC and associated environmental variables. Coloured areas map onto North Sea regions

## Links with site specific process studies - North Sea carbon cycling

- Within the North Sea there are significant areas where carbon cycling is mediated by advective flows through the bed rather than bioturbation.
- The conceptual model that describes carbon cycling in relation to redox needs to be extended beyond soft sediments – Figure 8.
- Detailed process studies support site aRPD/BPC placements but are not appropriate for indicator application (see figures 9,10 & 11).

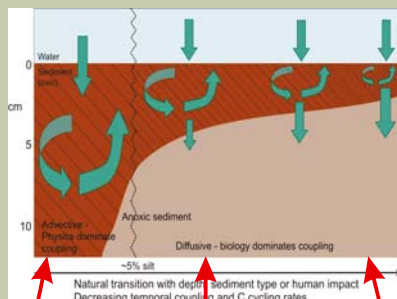


Figure 8. Conceptual model for North Sea sediments - combined redox and C cycling/coupling

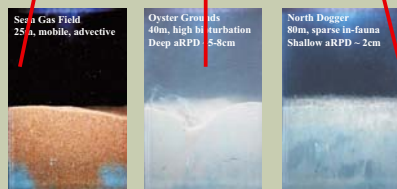


Figure 9. SPI images. From 3 North Sea sites and locations on C cycling conceptual model

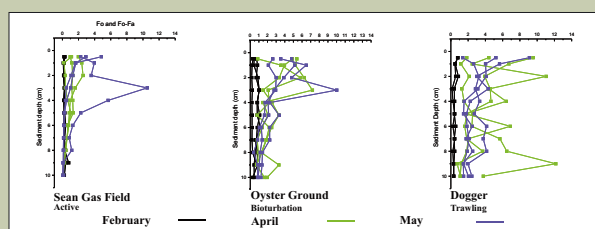


Figure 10. Chlorophyll profiles (fluorescence) for three North Sea sites

Measures	Sean Gas Field	Oyster Ground	North Dogger
Sediment type	Sand, mobile Advective pore-water	Muddy sand, stable, diffusive pore-water	Muddy sand, stable, diffusive pore-water, trawled
Redox	Highly aerobic, OPD >6-7cm physically mediated	Deep aRPD ~ 5-8cm, OPD ~ 1cm	Shallow aRPD 2-3cm. OPD ~ 1cm
Fauna/bioturbation	Sparse infauna	High faunal biomass, high bioturbation <i>urchins, Callinassa, Amphipura</i>	Sparse infauna, low bioturbation
C incorporation - turnover pathway	Rapid C incorporation, mixing, aerobic turnover - fast	Rapid C incorporation - bioturbation, O <sub>2</sub> and N cycles dominant	Time delayed C incorporation - trawling, SO <sub>4</sub> reduction significant (slower turnover)
Coupling	High - physical	High - biological	Event timed - trawling

Figure 11. North Sea site summary of sediment carbon cycling and coupling

## Conclusions

- ARPD/BPC approach has merit for soft sediments
- Co-location of datasets is an issue – key for monitoring needs
- ARPD - rapid assessment, regional SPI image library building
- BPC - can be calculated from existing data sets, needs calibration (t/f-SPI) and further testing (combinations, power)
- Regional macroecological modelling approach can lend itself to modelling effects of biodiversity change on function (aRPD and C cycling)
  - Within regions, rate of change, tipping points, key species
  - Setting activity limits to maintain function
- Linking detailed process measurements, which can describe sediment function (carbon cycling, bioturbation), with simpler regional functional indicators remains challenging.
- Rationalising varying complexity levels of modelling approaches that provide the spatial context is key.

## Acknowledgements

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## References

- European Commission (2007) Protection and conservation of the marine environment: framework for Community action, Marine Strategy Directive (93/88/2007 - CG-0261/2007).  
Pearson T.H. and Rosenberg, R. 1978 Macrobenthic succession in relation to organic pollution. *Oceanogr. and Mar. Biol.: Ann Review* 16: 229-311. *Science*, 306: 1177-1180.