Conceptual approaches to ecosystem-based sediment management

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Introduction

The adoption of the Ecosystem Approach to the management of human activities has introduced an increased complexity into the European policy and legislative framework at national and international levels. Linking human activities to ecosystem biodiversity, functioning (services) and adaptive management (via indicators) are key themes across various temporal and spatial scales. Management and impact assessment frameworks capable of integrating these concepts alongside key processes measurements are required to enable managers to make decisions which are consistent with the sustainability goals of this approach. Some examples of linking conceptual, impact assessment frameworks and processes measurements are demonstrated here. This example focusses on the cycling of carbon and nutrients and the role that the seabed and associated benthic biota play in this ecosystem service.

Policy and conceptual frameworks

Benthic biota are critical to a number of ecosystem services[1], including…

Provisioning services
Animal food; medicine and models for human research; fuels and energy (on geological time scales); and clean water

Regulating services
Remineralization; water treatment; biological control, gas and climate regulation; water disturbance regulation and erosion and sedimentation control.

Habitat maintenance services
Landscape linkages and structure; habitat and refugia

Aesthetic services
Recreation; tourism and education

To date many existing and proposed WFD and European Marine Strategy Directive indicators of benthic ecosystem status are based upon ***community structure***.

- However, benthic community structure is highly dynamic, and sensitive to a variety of factors.
- "It is probable that the ***diversity of function*** is more important for the sustainability of ecosystem goods and services than species diversity *per se*…"
- There is a need to understand benthic community ***functions***, their response to pressures, and their relationships to ***ecosystem services***

A useful conceptual model is one first proposed by Costanza[2] which documented that overall ecosystem health should include 3 components which could be used as metrics for ecosystem response to pressures;

- **Vigour** (throughput or productivity of the ecosystem)
- **Organization** (species diversity and complexity of trophic and other interactions),
- **Resilience** (an ecosystem's ability to maintain structure and patterns of behaviour in the face of stress)

A healthy ecosystem, then, is one that is actively producing (V), maintains its biological organization over time (O), and is resilient to stress (R).

Although Costanza proposed detailed quantitative indices for these factors, they can also provide a narrative framework or "triad" under which to organise structural or functional measures. Tett *et al.*,[3] built upon this framework when addressing the impact of eutrophication in the light of 'undesirable disturbance'. As pressures are introduced and/or removed, community structure and function respond based upon resistance and resilience. However, the original model assumes that systems can return to an original state – in reality, the final state may be different than the original one. Figure 1 illustrates such an update from Elliott *et al.*,[4]. This conceptual framework recognizes that ecosystem "health" or status cannot be represented as a univariate index, but rather is represented by a complex set of structural and functional measures. Recovery of these characteristics after a perturbation may be partial or total, and it is a complex set of these parameters that affect the delivery of ecosystem services. Research on, and measurement of the response of benthic community structure and function to various perturbations is needed and is the aim of an integrated EU FM6 programme called COBO.

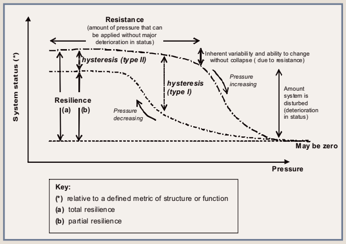

Figure 1: Conceptual framework to trace ecosystem structure and function response to pressure[4]

Integrated structure and function measurements

Coastal Ocean Benthic Observatory (COBO)

COBO is an EU FM6 funded programme to provide and test tools for *in situ* studies of the responses of benthic ecosystem structure and function to natural and simulated perturbations. Figure 2 (a to e) illustrate some of the tools developed under this project and the types of measures that can be taken. Table 1 documents how integrated COBO tools can be applied to study various biological, chemical and physical responses to human pressures, whether simulated or "real". COBO measures have also been matched in terms of their relevance in space and time to human and natural disturbances. Figure 3 illustrates this comparison between time and space scales for various human disturbances and COBO tool capability. Overall, COBO disturbance simulations are best for assessing impact on local and short term processes or acute effects. For chronic and larger scale effects COBO tools can be deployed on disturbance gradients and over recovery timescales.

For more detailed information look on www.cobo.org.uk

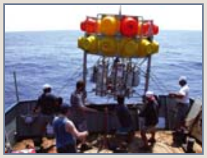

Figure 2a: Biogeochemical lander (MPIMM)

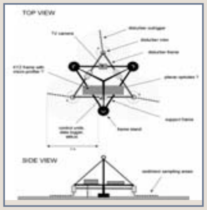

Figure 2b: Integrated sediment disturber – ISD (AWI & Cefas)

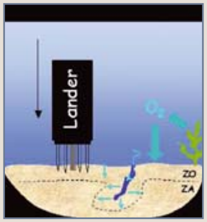

Figure 2c: Lander with microprofiler; conceptual drawing (LCSE)

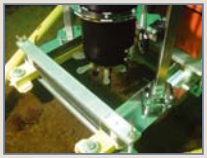

Figure 2d: Lander with microprofiler (LCSE)

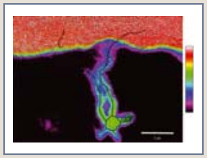

Figure 2e: In situ image of organism effects on oxygen dynamics (U-COP)

Table 1: Matrix of COBO tool applications relevant to human pressure

Pressure	Simulation[1]	Spatial gradient[2]	Temporal gradient[3]
Resuspension	ISD, resuspension chamber	Yes	Yes
Trawling	ISD?	Yes	Yes
Organic enrichment	Injection chambers	Yes	Yes
Eutrophication	Injection chambers	Yes	Yes
Anoxia	Benthic chambers / anoxic injections	Yes	Yes
Chemical contamination	Injection chambers	Yes	Yes
Xenobiotics / Invasive species	Not in field	Yes	Yes
Habitat loss	Not in field	Yes	Yes

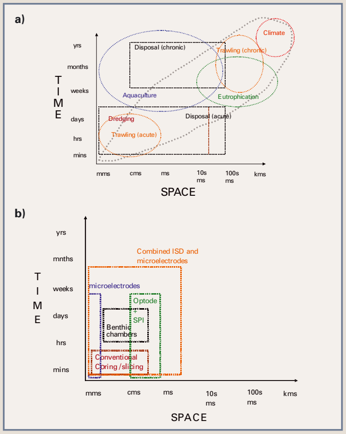

*Figure 3: Time and space scale comparison diagrams for **a)** anthropogenic impacts – natural processes envelope in grey, **b)** addressed by COBO tools*

Impact assessment tool – combined DPSIR & GIS

UK regulators need tools to assess overall impact of human activities on seabed function and components thereof. There are few conceptual frameworks or models that can be used to bring together all the relevant information (i.e. conceptual impact framework and functional measurements) in a form to permit impact assessment and investigation of management options (ecological targets) at appropriate spatial and temporal scales. Such an approach was developed by Cefas as part of a Defra study on the ecosystem consequences of seabed disturbance on key seabed functions. The main aim was to develop an improved method for conveying information on impact assessment to regulators, policy makers and the public. A GIS-based framework was used to underpin the conceptual models and facilitate scenario testing.

The GIS assessment tool comprises four components:

- Overall conceptual framework based on the DPSIR (**D**riving force, **P**ressure, **S**tate, **I**mpact, **R**esponse) approach to assessing ecosystem 'health' (from OECD and EEA).
- Parameterisation of disturbances – **D**river, **P**ressure (natural, anthropogenic, single, composite, timing, real/scenario, mode of impact, chronic vs. acute)
- Impact models – to describe the effects of physical disturbance on the ecosystem function (sediment geochemistry / benthic fauna, algal cyst viability, contaminant release) - **S**tate, **I**mpact.
- The integrating framework (GIS based) - allows analysis of spatial information, derivation of cause/effect models and testing of models in a spatial matrix with respect to impact questions (**R**esponse).

A schematic of this framework, the associated GIS layers and linking models is depicted in Figure 4.

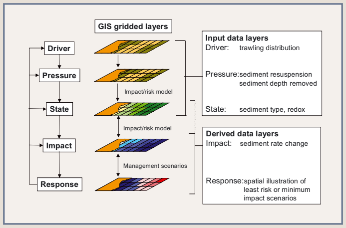

Figure 4: Schematic of the GIS based tool for scenario testing impact of human activities

The DPSIR and GIS-based framework can be used to evaluate the regional-scale benthic ecosystem impacts of various management actions. The relevance of structure or functional impact models (impact/risk model) will be greatly enhanced by *in situ* benthic impact studies such as those carried out using COBO tools. An example of an application of the framework to examine changes in sediment C budgets as impacted by trawling appears in Figure 5.

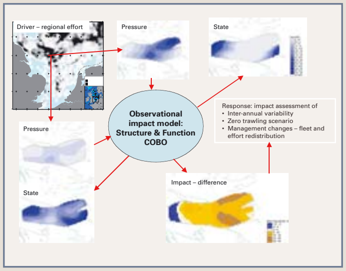

Figure 5: Example of application of the DPSIR/GIS framework to assess regional impact of trawling on sediment carbon budgets

Conclusions

- Need to link ecological response to sustainable management.
- "Quantitative information gained at the multi-species level from a number of robust experiments at small and large spatial scales and longer temporal scales must be conducted regionally and globally for a greater predictive capability concerning threats to, and controls on, different ecosystems and their services"[1]
- "A priority for future research is incorporating effects of multiple stressors into experiments regionally"[1]
- Impact assessment tools are still somewhat sectorally based in terms of a focus on benthic habitats and impact on state. The future challenge is to extend these approaches to incorporate benthic and pelagic components via biodiversity and functional indices which allows the integrated assessment and sustainable management of multiple human pressures.

References:

1 Wall DH (ed). 2004. Sustaining Biodiversity and Ecosystem Services in Soils and Sediments. Washington D.C.: Island Press. 275 p.

2 Costanza R. 1992. Toward an operational definition of health. In: Costanza R, Norton B, and Haskell B (eds), Ecosystem Health: New Goals for Environmental Management, pp 239-56. Island Press, Washington, DC, USA

3 Tett P, Gowen R, Mills D, Fernandes T, Gilpin L,Huxham M, Kennington K, Read P, Service M, Wilkinson M *et al*. In press. Defining and detecting undesirable disturbance in the context of marine eutrophication. *Marine Pollution Bulletin*

4 M Elliott, D Burdon, K L Hemingway and S E Apitz (2007) Estuarine, Coastal and Marine Habitat and Ecosystem Restoration: confusing management and science, accepted by Estuarine, Coastal and Shelf Science.

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