Biogeochemistry, macronutrient and carbon cycling in the benthic layer (BMCC)

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Overview: There is a requirement for quantitative knowledge on what the current annual exchanges of carbon are between UK/European shelf seas and the open ocean, whether shelf sea sediments act as a source or sink for macronutrients (N, P, Fe and Si), what the physical and biogeochemical controls on shelf productivity and community composition are, and how these exchanges influence one another and interact with anthropogenic and climate related change. Our main activities will focus on the Celtic Sea and will combine (i) a detailed study of representative shelf sea landscapes that spans the full variety of biogeochemical conditions typically observed in temperate shelf seas, with (ii) broad-scale *in situ* validation studies, and (iii) manipulative laboratory and field experiments aimed at unambiguously identifying causal relationships and establishing generality, and (iv) integration of new understanding of controls and effects on carbon (C) and nutrient cycles into modelling approaches (empirical, GIS, ERSEM) to disseminate baseline biogeochemical function at regional scales and under changed conditions. The relative size (stock) of the C and macronutrient pools, microbial transformation rates and fluxes between pools will be quantified in shelf sediments during 3 integrated cruises (pre-bloom Spring, post-bloom early Summer and Winter) scheduled to coincide with contrasting OM supply (nutrient and plankton cycles), water column structure (mixing versus stratification, current and tidal resuspension) and biogeochemical conditions (diffusion, advection, biota mediated processes) across representative habitat types of the UK and European shelf.

Using dedicated research cruises we will directly quantify the pools and exchanges of macronutrients (N, P, Fe, Si) and C across a range of sediment habitats using an extensive range of physical, biological, chemical, acoustic and optical techniques in order to gain a holistic understanding of the biogeochemistry of shelf sea systems. We will combine these observations with an extensive series of manipulative laboratory and field experiments aimed at linking multiple aspects of change (temperature, ocean acidification, tidal and storm induced resuspension, trawling intensity) with changes in naturally assembled communities associated with altered habitat condition (cohesive to non-cohesive sediments) and water column stratification (stratified vs mixed). We will then establish how these interact to affect the stocks and flows of C and macronutrients, in a representative natural shelf sea system.

Module 1: Biogeochemical cycling of sediment N, P, Si and C

This module will quantify nutrient and C dynamics within cohesive and non-cohesive sediments over short timescales (mins to yrs) and examine the relative importance of different sediment types. The first task will utilize ship-based incubation and percolation/flow-through systems to determine the role of temporal and environmental variability in setting rates of elemental cycling (Task 1.1). A suite of molecular approaches will be used to identify changes in microbial community structure and in specific nutrient (N and S) cycling functional guilds that drive seasonal and habitat variability observed in the following task (Task 1.3). The extent to which changes in the quality and quantity of organic material supplied to the benthos from pelagic export contributes to temporal and spatial variability will be determined by comparing the stoichiometry (C:N:P:Si) of exported POM to that of the net flux of inorganic solutes leaving the sediments. Dual isotope ($^{13}C/^{15}N$) enrichment experiments (Task 1.4) will be conducted to quantify the rates at which freshly deposited POM cycle and the groups of organisms responsible. Understanding from these first 3 tasks will quantify elemental cycles within undisturbed sediments, which will be compared with data generated from experimental simulations of sediment resuspension events (to mimic the impact of demersal trawling, tidal currents or storms; Task 1.2). This will determine the relative importance of such stochastic events for annual estimates of biogeochemical cycling within the different seabed habitats (Task 1.5).

Module 2: Role of sediments in C storage. Continental shelf sediments are responsible for burying >1 × 10^{14} g C yr^{-1}, mostly in soft, cohesive sediments. Many benthic organisms are heavily calcified and, collectively, constitute an important sink for carbon in shelf seas and globally, especially in advective non-cohesive sediments where the majority of deposited organic matter is rapidly mineralized. C accumulates in sediments as detrital material, organismal biomass and inorganic minerals. Module 2 aims to quantify these pools of C in the sediments at contrasting sites and seasons and determine the relative importance of these over annual to multi-decadal timescales. We will collect data from field cruises to quantify the relative distribution of C within the detrital (Task 2.1) and biological (Task 2.2) pools. We will also provide data to support estimates of productivity, respiration and community function. Task 2.3 will quantify the role of sediments in long-term C storage through burial of organic and inorganic C. Task 2.4 will model long-term C storage under different scenarios.

Module 3: Role of macrofauna and the impacts of natural and anthropogenic disturbance on sediment biogeochemical processes. This module focuses on the role of macrofaunal invertebrates in mediating the cycling of key elements within the seabed and will quantify the infaunal contributions to, and control of, C and nutrient dynamics within cohesive and non-cohesive sediments in natural (Aim 3.1) and anthropogenically disturbed (Aim 3.2) shelf sediments. Aim 3.1 recognise that the burrowing and ventilation activities of infaunal organisms can have a significant impact on biogeochemical cycling in shelf sediment habitats, by increasing the oxygen availability and redox conditions in the sediment and enhancing microbial process rates that affect sediment C- and nutrient cycling. Aim 3.2 focusses on quantifying how bottom trawling and climate change directly and indirectly affect C and nutrient cycling through changes in macrofaunal community structure. Hence, we will examine the relationship between fauna-microbe-process rates, and examine whether this relationship is modified by anticipated anthropogenic and climatic disturbances.

Module 4: Impacts of sediment resuspension and near-bed current flow on carbon and nutrient sediment-water exchange in diffusive and pumped sediments

Shelf seas are energetic environments. Frequent resuspension and reworking are caused by natural events such as winds, waves, tidal currents and biological activity, and by anthropogenic perturbations such as trawling and dredging, which affect biogeochemical pathways and timings. Quantifying their role in fluxes and transformations is crucial for assessing how shelf-sea ecosystems function, and predicting how they are likely to respond to future changes. Traditional techniques used to measure the exchange of nutrients and other bioactive solutes between benthic and pelagic zones, such as *in situ* benthic flux chambers, whole core incubations, and the flux calculations based on chemical gradients near the sediment-water interface, only produce passive fluxes due to processes such as molecular diffusion. More complex physical processes, such as sediment resuspension and water advection, are often overlooked and are still relatively poorly understood due to a lack of observational data. Bioturbation and bioirrigation also receive little attention, but have recently been taken into account and are being assessed in Module 3 of this programme. This module aims to improve our understanding of diffusive and pumped sediment water exchange of dissolved components, sediment resuspension processes and associated biogeochemical processes. We will assess *in situ* variations in nutrient concentrations and how nutrient sediment-water exchange is affected during resuspension events (diffusive) or increases in near-bed current flow (pumped) in order to elucidate the benthic-pelagic coupling of macro-nutrients and associated processes using a series of *in situ* and on-board ship measurements. We will also assess the effect of sediment resuspension (including trawling) and increased near-bed flows (and other components of the hydrodynamics) on sediment-water column exchanges of macronutrients and C cycling. As shelf Sea ecosystems are particularly vulnerable to many of the projected effects of climate change such as sea level rise, increased air and water temperatures, changes in precipitation and storm intensity, and ocean acidification, it will also be important to project potential sensitivity to anticipated future environmental conditions. Using the new data we will collect from our laboratory and field experiments, we can scale-up our findings to estimate changes in regional carbon and nutrient fluxes across the SWI for different substrates, regions and storm/trawl gear distributions. Informed by our observations and experiments, present day and future scenarios of trawling distributions will be tested alongside future climate forcing to address the net effects of trawling and resuspension on regional scale C and nutrient fluxes and budgets.

Collectively, our overarching objectives will allow us to establish the generalities of how abiotic and biotic interactions, including feedbacks and linkages, will affect macronutrient and carbon exchange in shelf sea systems, including responses to anthropogenic drivers and climate change.

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