Productivity in past and future oceans

What ancient crises tell us about future threats to marine ecosystems

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Synopsis

The world's oceans and their ecosystems are under threat from anthropogenic activities that are interacting to produce complex changes like never before. IPCC modelling of near future oceans predicts a variety of extreme environmental and ecological changes including an imminent "productivity crisis" whereby anthropogenic nitrogen (N) discharge from agricultural practices, wastewater treatment, fossil fuel and biomass combustion drives eutrophication and unpredictable, changing patterns in global marine productivity (Fig. 1). The dramatic increase in N discharge since pre-industrial times has altered the balance of the marine fixed-N inventory and will change productivity in future as global populations and demand for resources continue to grow. Confounding factors driven by climate change are likely to reduce productivity in key continental-margin ecosystems with major implications for atmospheric CO_2 (which is sequestered as carbon in the oceans) and global warming. These synergistic stresses will dramatically reduce biodiversity with catastrophic results for marine ecosystems and ecosystem services. Of even greater concern is that we do not understand how, and over what timescales, marine ecosystems will respond, because models are inadequate.

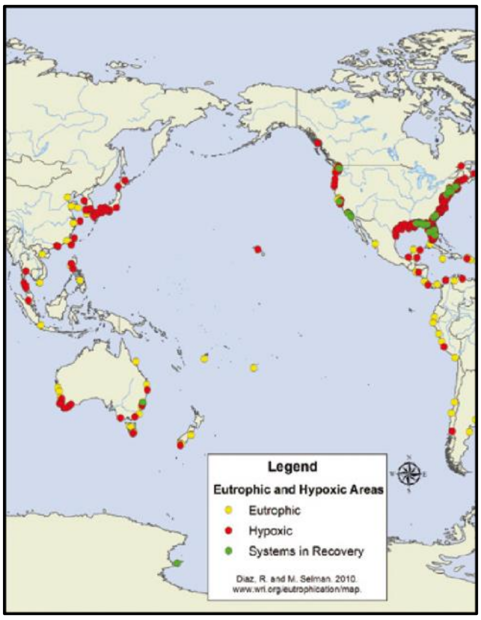

Fig. 1: areas of eutrophication include some of the world's most fragile and economically important ecosystems (Diaz & Sellman, 2010).

Earth history records numerous examples of N-cycle perturbations that probably occurred – and had impacts persisting – over timescales orders of magnitudes longer (Myr not Kyr) than those predicted for modern oceans. These purported ancient crises are associated with the greatest mass extinctions, suggesting a causal link between these phenomena. Models of modern oceans might hugely underestimate temporal, spatial, and ecological scales of the impending crisis.

There is a clear mismatch between forecasts for the modern and ancient: it has been suggested that atmospheric N fixation will relieve N limitation in modern oceans, stimulating primary production that in turn sequesters carbon in the oceans, buffering rising atmospheric CO_2. In contrast, deep time has experienced runaway greenhouse conditions (e.g. Early Triassic, 250 Ma) associated with the cessation of upwelling along continental margins, a reduction in marine productivity and a deepening of the nutricline, reducing the rate of photic zone nutrient delivery and suppressing diversity and carbon burial. We need to understand the long-term interactions between global warming, productivity, and the global C and N cycles in order to predict the impact of changing dynamics in Earth's future.

This project will evaluate causes and consequences of N-driven productivity crises in the geological record and their links to multiple marine mass extinction events through a combination of novel and standard geochemical and palaeontological methods.

Aims and objectives

Models predict an impending productivity crisis driven by anthropogenic atmospheric N discharge acting synergistically with climate change and lasting for thousands of years. The damage to global biodiversity might be catastrophic. To understand if these predictions are accurate, we urgently need to examine past examples of productivity crises to calibrate our expectations. This will involve a series of key research questions:

1) Have marine productivity crises happened in the geological past – and if so what is their link to mass extinction events (are they e.g. a common feature of these)?

Revealed by geochemical and palaeontological studies of marine sequences deposited in palaeo-continental margin settings (sites of upwelling and flourishing life) across major, but stylistically contrasting extinctions: the Late Devonian (ca. 372 Ma), the end Devonian (ca. 360 Ma), Middle Permian (ca. 260 Ma) and end Permian (ca. 252 Ma) catastrophes.

2) How environmentally widespread and long lasting were past productivity crises?

The above establishes a temporal framework for records of past productivity crises. Analyses from a range of marine settings will establish the spatial extent and variability of these events.

3) What environmental and climatic factors drove past productivity crises?

Further geochemical and sedimentological analyses of the sample suite, complemented by geochemical modelling, will test for common factors in the development of productivity crises.

4) What was the impact of past productivity crises on ecosystems?

This will be examined through careful comparison of the geochemical and sedimentological records to those of faunal losses and recovery during the five extinction events. Although it is difficult to disentangle the synergistic effects of global warming, acidification and anoxia from those of productivity, the project will test whether productivity crises are a common, causal or consequential factor in major mass extinction events.

5) What do these questions mean for models and predictions of Earth's near future?

The results will be used to verify modern models (e.g. IPCC). It might be that predictions of near-future productivity crises vastly underestimate their potential temporal and spatial scale and ecological impacts. If so, we need to revise our predictions and mitigation strategies.

Methods

Field collection of samples for geochemical and palaeontological analyses from marine palaeo-continental margin settings (e.g. western N. America, Arctic Canada, S. America) will be complemented by a vast archive of materials stored at Hull, Leeds and the Geological Survey of Canada. Our collections of >5,000 samples spanning the Ordovician, Late- and end-Devonian, Middle- and end-Permian extinction are an outstanding resource that make this project feasible.

Mixed geochemical methods include analysing N and Cd isotopes (by GS-IRMS and ICP-MS), trace metals (e.g. biogenic barium [Ba_{bio}], by ICP-MS and XRF), phosphorus concentrations (by sequential extraction) and total organic carbon (analysed by Rock Eval™) as proxies for marine productivity. These are supported by excellent facilities in Hull, Leeds and Canada, including state of the art mass spectrometry, XRF, elemental analysers, Rock Eval™, and electron microscopy.

Constraining extinction losses and timing for each of the five extinctions under scrutiny relies on fossil identification in the field and thin section. Linking these independent changes reveals the timing and consequences of change. These techniques complement the novel geochemistry, and are supported by thin section laboratories at Hull and Leeds.

This approach and the scale of the project is highly ambitious, but made feasible by (1) the extensive expertise of the team; (2) the outstanding repository of samples already available; and (3) the excellent, international-standard geochemical facilities available at the institutions involved.