

Meeting title	Upper Ocean Nutrient Limitation: Processes, Patterns and Potential for Change			
Working Group	WG1			
Meeting convener	First name	Mark	Surname	Moore
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Meeting dates	3 rd – 5 th November 2010			
Meeting location	Institute	National Oceanography Centre, Southampton		
	City	Southampton		
	Country	UK		

Meeting background and aims
<p>The meeting was put together under the auspices of an IGBP Fast Track Initiative. Nutrient limitation of upper ocean productivity exerts a fundamental control on deep ocean carbon storage and hence ultimately atmospheric pCO₂. Over the past 2 decades a number of significant advances have furthered our understanding of the processes responsible for patterns of nutrient limitation in the upper ocean. However fundamental controversies remain. Moreover there are uncertainties concerning the likely magnitude (and even sign) of future changes in key nutrient sources, which must be carefully considered in the context of the primary limiting factors within the oceanic regions they will influence. Much of the current confusion likely stems from frequent inconsistencies in the assessment of, and even use of, the term 'limitation', potentially hindering the recognition of processes and generic patterns, and generating a barrier on effective communication between, for example, observationalists, modellers and potentially paleo-oceanographers.</p> <p>Consequently it appeared to be an opportune moment for the community to attempt to clarify the current observational situation. Moreover, given the large number of recent studies and advances, for the first time it was potentially possible to provide the a large scale integrative assessment of the spatial variability in dominant limiting factors across the major ocean regions and hence relate these to large scale circulation patterns and nutrient cycling. Such a synthesis was hoped to provide a powerful framework against which potential future and past changes in nutrient inputs could be assessed. Additionally, it was felt that a number of large international observational programmes including aspects of SOLAS, IMBER and GEOTRACES could potentially benefit from identification of any major observational gaps.</p> <p>Overall the meeting was intended to asses the following four linked goals:</p> <ol style="list-style-type: none"> 1) To provide a synthesis of the current state of knowledge concerning patterns of upper ocean nutrient limitation, including identification of current observational gaps, taking specific account of (3) and (4) below. 2) To use (1) to make recommendations for future avenues of research, including those which can potentially only be addressed via large integrated international programmes, taking specific account of the potential for past and future global change and linkages to the carbon cycle.

3) To make recommendations for a rigorous definitional framework for describing upper ocean nutrient limitation, with specific reference to multiple timescales and cross disciplinary boundaries (e.g. observations vs. modelling).

4) To critically evaluate the techniques and methods currently used for assessing upper ocean nutrient limitation, with specific reference to precise definitions (3).

Summary of discussions

The workshop was attended by 19 participants from 10 countries, with 2 participants having to pull out due to illness. The range of different disciplines and level of expertise present facilitated a dynamic environment for stimulating and productive cross disciplinary discussions.

Prior to the meeting the participants were separated into working groups and asked to prepare ~6 page reports on 9 themes covering the various topics to be covered. The set questions were: 1. What is meant by the term 'limitation'? 2. How is nutrient limitation assessed in the laboratory and the field? 3. What are the physiological and biogeochemical mechanisms by which co-limitation can occur? 4. How is nutrient limitation represented in large scale models? 5. What elements and compounds need to be considered in any assessment of potentially limiting nutrients? 6. What is our current state of knowledge concerning the large scale patterns of nutrient limitation for different groups? 7. How does nutrient limitation in the upper ocean influence the global carbon cycle? 8. What can we learn from paleo studies of nutrient availability? 9. What major changes in potentially limiting nutrients do we expect over the rest of the century? What will the spatial distribution of these changes be?

The first day of the workshop was dedicated to the presentation and subsequent discussion and deliberation of these topics. A large range of material was covered in detail, the reports and presentations are currently available to participants within a secure region of the website, with future wider dissemination in mind.

At the start of the second day, a plan for taking the discussion forward was formulated, paying particular attention to expected outputs. The group discussed whether the full range of material could successfully be covered within a single review article and it was agreed that many of the developed cross-cutting themes would have been lost if outputs were split. Biogeochemical modellers present at the meeting also suggested that any synthesis of currently available fieldwork indicating large scale patterns of nutrient limitation would likely become a key resource for model validation. An overall plan for a potential review was thus formulated and the group was split in half. The first sub group was charged with discussing:

concepts and definitions of nutrient limitation and current patterns of limitation

while the second sub-group discussed:

expected changes in the future and implications

Following lunch on the second day, sub-groups reported back in plenary on outcomes of the morning discussions. The first working sub-group had further considered definitions and concepts of limitation and initiated work towards building a database of current knowledge on large scale patterns of nutrient limitation, pulling together results from nutrient manipulation experiments and known patterns of nutrient availability. The second sub-group had concluded that paleo case studies within a review would be useful for highlighting the potential for significant changes within the system. The second group had then identified potential changes over a timescale restricted to the end of the century. Changes were split into three categories, the first associated with increasing surface ocean

temperatures associated with global warming, the second associated with increasing surface water CO₂ concentrations driven by increasing atmospheric concentration and the third associated with changes in external supply of nutrients to the oceans.

At this stage it was decided that sufficient structure was in place for the assignment of initial writing tasks. Individuals and sub-groups then spent the remainder of the day further discussing and writing sections for a final review.

At the start of the third day the whole group considered potential future research directions further. An interesting general discussion covered topics ranging from locations and prevalence of the nutrient time-series which might be required to monitor future changes, to increased use of molecular techniques as diagnostics of nutrient stress.

The group then moved on to discuss whether strong statements on the scale and timescales of any changes to the system could be made. The group further considered whether longer timescale implications should be included, eventually deciding to keep such discussions to a minimum. It was recognised that a key aspect of any review would involve clarifying time and space scales over which specific processes operate.

Individuals and groups then continued with writing assignments before a final wrap up session and the end of the workshop.

Meeting Outcomes

The working papers and presentations concerning specific questions already constitute a major outcome of the meeting. Moreover the synthesis of this material performed within the meeting will form the basis of a review which is likely to mark a significant statement on the current state of the art.

Future outcomes are set to include a major review paper. A range of brief meeting reports will also be prepared including one for the SOLAS newsletter. Given the limited space likely to be available within the review, a number of individuals and groups also expressed a desire to work on writing up some of the additional material within more specialist reviews.

Goals and plans for future activities (please include details of further meetings, publications research proposals and a timeline for these activities)

The principal short term goal will be the writing and submission of a major review within a high profile journal. Initial discussions with the editor concerning publication in *Nature Geoscience* have already been positive. The whole group will thus be working towards a hopeful submission date within the first 2 months of 2011. As mentioned above, further specialist reviews may be forthcoming.

Any other comments

In addition to the money provided by IGBP, additional funds were secured from the US OCB programme and from EU-COST 735. In the end 2 workshop participants were supported by COST funds.