

Fast-Track Initiatives

FTI Application Form - Section 1	
<i>Please fill in as indicated below. Maximum 1 page</i>	
Coordinator and affiliation	Dr. Mark Moore (NOCS, UK)
Co-coordinator(s) and affiliation(s)	Dr. Matt Mills (Stanford University, USA) Prof. Doug Wallace (SOLAS) Dr. Emily Breviere (SOLAS)
IGBP SC liaison*	Prof. Doug Wallace (SOLAS)
Title of the FTI	
Upper ocean nutrient limitation: processes, patterns and potential for change.	
Goals, key questions and knowledge gaps	
<p>The proposed FTI has 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). 	
Products	
<ol style="list-style-type: none"> 1) Publication of an authoritative general synthesis and review of the current state of knowledge of upper ocean nutrient limitation in the peer reviewed literature e.g. in <i>Science</i> or <i>Global Change Biology</i>. 2) Production of more detailed reviews on specific topics, e.g. concepts and cases of co-limitation, critical future changes in limiting nutrients. 3) Recommendations for large scale observational and/or modelling programs addressing identified knowledge gaps which can potentially be implemented within (or cross cutting) IGBP Core programmes. 	
Management	
Moore, Mills and Breviere, will be responsible for organising the workshops. Moore and Mills will coordinate product delivery. Budget management will be performed by Breviere and Moore. Wallace will report to IGBP.	
Link to IGBP projects	
The proposed FTI cross cuts themes within IMBER, SOLAS and AIMES	
Timeline and tentative budget	
Feb 2010: dedicated session at the joint AGU/ASLO conference in Portland Oregon. Late 2010/early 2011: dedicated workshop. Mid 2011/mid 2012: manuscript preparation and submission, final reporting. Funding will be required for 15-20 invited attendees at the workshop (estimated average 1000euro each). A total of 12000 euro is requested for the FTI, with an undertaking to explore the potential for joint funding from SCOR, SOLAS and UK-NERC/SOFI and NSF.	

FTI Application Form - Section 2

Please fill in as indicated below. Maximum 3 pages

Background and rationale

Nutrient limitation of upper ocean productivity exerts a fundamental control on deep ocean carbon storage and hence ultimately atmospheric pCO₂ (Falkowski, 1997; Marinov et al. 2008a&b). Many significant advances have furthered our understanding of the processes responsible for patterns of nutrient limitation in the upper ocean over the past 2 decades. For example: the unequivocal demonstration that iron limits phytoplankton in the so called high nutrient low chlorophyll (HNLC) regions (Boyd et al. 2007), potential variability in nutrient stoichiometry (i.e. non-Redfieldian behaviour) and evidence for simultaneous co-limitation of microbial productivity by multiple limiting resources (Arrigo, 2005), have all altered our views of the traditional proximal and ultimate limiting nutrients (c.f. Tyrrell, 1999). Indeed, it is now widely accepted that the influence of upper ocean biota on the biological component of air-sea CO₂ partitioning is influenced by the limiting potential of at least the elements N, P, Fe and Si, as well the complex interactions between them (e.g. Sarmiento et al. 2004; Arrigo, 2005; Deutsch et al. 2006).

However, fundamental uncertainties and controversies remain. Examples include; the nutrient(s) that limit nitrogen fixation in the modern ocean and thus, through the feedback with the oceanic fixed N inventory, the identity of the ultimate limiting nutrient in both the modern and paleo ocean (Tyrrell, 1999; Falkowski, 1997; Deutsch et al. 2006). Likewise, frequent suggestions for other potentially biolimiting factors, including trace elements other than Fe (Saito et al. 2008), carbon availability (Riebesell et al. 2007) and organic biomolecules (Sanudo-Wilhelmy et al. 2006), all require further confirmation as significant controls of ocean productivity. Consequently the overriding patterns of nutrient limitation currently remain obscure. Such a situation may restrict progress in many areas including, but not limited to, the development of complex physio-biogeochemical models (Moore et al. 2004) and predictions concerning the oceanic response to on-going anthropogenic forcing (Jickells et al. 2005; Duce et al. 2008). The latter are further confounded by uncertainties concerning the likely magnitude (and even sign) of future changes in certain key nutrient sources (Jickells et al. 2005), which must be carefully considered in the context of the primary limiting factors within the oceanic regions they will influence.

Much of the potential confusion likely stems from frequent inconsistencies in the assessment of, and even use of, the term 'limitation'. Despite significant attempts to provide more rigorous definitions of terms (Cullen, 1991; Arrigo, 2005; Saito et al. 2008), there remain highly significant semantic differences within the literature concerning the use of the term 'limitation'. Indeed any definitional framework, encompassing more precise terms such as 'stress', 'starvation', 'Liebig' and 'Blackman' type limitation, should fundamentally take account of both the ecophysiological processes being considered and the methods which are appropriate for assessing these processes in a given

situation. However, such precision is all too frequently absent, resulting in confusion within the observational literature, 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.

Consequently it is an opportune moment for the community to attempt to clarify the current observational situation and synthesise recent studies concerning non-traditional nutrient interactions (Arrigo, 2005). Moreover, given the large number of recent studies and advances, for the first time it is 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 would hopefully provide a powerful framework against which potential future and past changes in nutrient inputs could be assessed. Additionally, a number of large international observational programmes including aspects of SOLAS, IMBER and GEOTRACES are ongoing alongside the small scale individual studies that suggest new potential limiting nutrients. Thus it would be timely to identify major observational gaps as well as recommend more standardised methods for the assessment of nutrient limitation in the upper ocean.

Major current societal issues are related to the proposed FTI. In particular there is persistent debate concerning proposals to artificially manipulate the oceans biological pump via the addition of limiting nutrients (Buesseler et al. 2008). Simultaneously, there is increasing recognition that humans are already involved in a massive unintentional perturbation of many of the major nutrient cycles in the upper ocean, both as a result of direct inputs (Duce et al. 2008) and changes in processes caused by, for example, increased stratification (Behrenfeld et al. 2006), changing circulation patterns, and increasing anoxia (Stramma et al. 2008). Due to the complex physio-biogeochemical factors influencing nutrient cycles, the ultimate consequences of such unintended and potential intentional manipulation of limiting nutrients are also likely to vary regionally. For example, major changes in macronutrient (N,P) or oxygen cycles might be expected to disproportionately impact low latitude systems and hence often coastal regions proximal to developing countries. Understanding the potential consequences of both unintentional and intentional perturbations in limiting nutrients is thus a clear prerequisite before informed policy decisions can be made. Overall the proposed FTI will thus address highly topical scientific issues, which potentially have major societal impacts.

Approach

The FTI will be implemented by a workshop in late 2010 or early 2011 with a synthesising high profile review and a number of more specialised reviews as the major product. The workshop will have around 25 participants, 15-20 will be invited experts in the field of upper ocean nutrient limitation, nutrient inputs or nutrient biogeochemistry. A small number (5-10) of places will be reserved for young scientists potentially from under-represented regions and countries. A general request will also be made for contributions to a proposed special session on co-limitation of upper ocean microbial processes convened at the

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joint AGU/ASLO Ocean sciences meeting in Oregon in February 2010. It is envisaged that a limited number of self-funded places will be made available at the main workshop, with potential participants recruited from the prior meeting. Organisation of the workshop will follow previous successful models (e.g. the global iron and nitrogen cycle FTIs (Jickells et al. 2005; Duce et al. 2008). A sub-committee will pose a number of working questions prior to the meeting. Participants will then be required to work in small groups to produce documents before, and presentations at, the meeting to provide a working framework and initial synthesis for subsequent breakout workshops.

Expected outcomes

The FTI will result in the publication of an authoritative general synthesis and review of the current state of knowledge of upper ocean nutrient limitation in a high profile peer reviewed journal. More detailed reviews on specific topics, likely examples being concepts and cases of co-limitation, or identification of critical future changes in limiting nutrients, will also be produced.

The FTI will make recommendations for large scale observational and/or modelling programs addressing identified knowledge gaps which can potentially be implemented within (or cross cutting) IGBP Core programmes.

Participants

Provisional (unconfirmed) list of suggested **participants** along with *expertise*:

Kevin Arrigo *Nutrient stoichiometry* (US, Male)

Illana Berman-Frank *Nutrient limitation of diazotrophs* (Israel, Female)

Laurent Bopp *Modelling, link to AIMES* (France, Male)

Phil Boyd *Phytoplankton Fe limitation* (New Zealand, Male)

John Cullen *Phytoplankton physiology, nutrient limitation* (Canada, Male)

Richard Geider *Phytoplankton physiology and stoichiometry* (UK, Male)

Cecil Guieu *Microbial nutrient limitation, atmospheric inputs* (France, Female)

Tim Jickells *Atmospheric nutrient inputs* (UK, Male)

Julie La Roche *Diazotroph nutrient limitation* (Germany, Female)

Tim Lenton *Modelling, nutrient stoichiometry* (UK, Male)

Natalie Mahowald *Atmospheric nutrient inputs, link to AIMES* (US, Female)

Emilio Maranon *Phytoplankton ecology and physiology* (Spain, Male)

Irina Marinov *Nutrient biogeochemistry, modelling* (US, Female)

Keith Moore *Modelling multiple limiting nutrients* (US, Male)

Tom Pederson *Paleo-oceanography* (Canada, Male)

Carol Robinson *Upper ocean microbiology, link to IMBER* (UK, Female)

Mak Saito *Nutrient co-limitation, trace metal bioavailability* (US, Male)

Shigenobu Takeda *Phytoplankton physiology, iron limitation* (Japan, Male)

Frede Thingstad *Bacterial resource limitation* (Norway, Male)

Oswaldo Ulloa *Phytoplankton ecology and biogeochemistry* (Chile, Male)

Interaction with stakeholders and the user community

The FTI will deliver an assessment of global and regional system sensitivity to changing nutrient inputs, informing the scientific user community and potentially future climate assessments (e.g. IGBP) and policy makers. Direct participation will be sought from policy/commercial stakeholders.

Other issues

N/A