THE ROLE OF CLIMATE CHANGE AND HYPOXIA IN THE SUDDEN EMERGENCE OF BLOOMS OF THE DINOFLAGELLATE *NOCTILUCA MILIARIS* IN THE ARABIAN SEA

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Abstract
The recent trend of global warming has exerted a disproportionately strong influence on the Eurasian land surface causing a systematic decrease in spring snow persistence over southwest Asia and the Himalayan-Tibetan Plateau region. Our study (*Goes et al., 2005*) shows that this decline in snow cover is causing a land-ocean thermal gradient favorable to stronger southwest (summer) monsoonal winds. Using a continuous record of satellite ocean color data we observed that chlorophyll *a* (Chl *a*) concentrations, an indicator of phytoplankton biomass, in the western Arabian Sea (AS) have increased three fold from 1998 onwards. We ascribed this record increases in phytoplankton blooms to escalation in the intensity of summer monsoonal winds accompanied by enhanced upwelling along the coasts of Somalia and Oman. In a parallel study (*Goes et al., submitted*) we have also observed that since 1998, winter convective mixing responsible for fertilizing the mixed layer, has been weakening but despite this trend, Chl *a* concentrations have been on the rise. Collaborative studies with India and Oman with the support from NASA and NSF have shown this increase to arise from unprecedented blooms of a green heterotrophic dinoflagellate, *Noctiluca miliaris (Fig.1) (Gomes et al., 2008; 2009)*. There are no previous records of *Noctiluca* from earlier studies which reported primarily diatoms as the major bloom forming phytoplankton in winter. Taxonomic and bio-optical data collected from 2003-2011 show that large-scale blooms of *Noctiluca* have become a regular feature of the AS appearing with remarkable consistency every year from Feb. to Mar. *N. miliaris* is distinguished from the ubiquitously-distributed *N. scintillans* by the presence of a large population of endosymbiotic prasinophytes (*Pedinomonas noctilucae*) housed within the cell. Hydrographic and chemical measurements since 2003 indicate that *Noctiluca* prefers waters that are cooler (< 24°C) and undersaturated in oxygen. Shipboard ecophysiological studies (NSF funded) conducted in 2011 have provided us with the first evidence that *Noctiluca* is able to photosynthesize more efficiently under low O_2 conditions (Fig. 2). Oxygen deficiency (< 4.5uM) at mid-depths (>120m – 1500m) is a unique feature of the AS and is the result of monsoon-driven high surface productivity of the semi-annual phytoplankton blooms, naturally low dissolved oxygen content sub-thermocline source waters flowing from the Southern Ocean and poor ventilation in the landlocked north. We suspect that the three-fold increase in phytoplankton in summer observed by us has contributed to expanding the Oxygen Minimum Zone. A comparison of oxygen saturation data from our present studies with historic data from an area bounded by 23-19°N and 64-69°W where *Noctiluca* blooms have been observed, suggests the Arabian Sea is becoming increasingly undersaturated with respect to oxygen. Another potentially large but unexplored source of organic matter to the Arabian Sea is domestic and industrial outfall from rapidly growing cities especially Mumbai along the west coast of India. Grazing studies during the 2011 cruise suggest that *Noctiluca* is not a preferred food because of its large size, and is consumed mainly by jellyfish and salps.

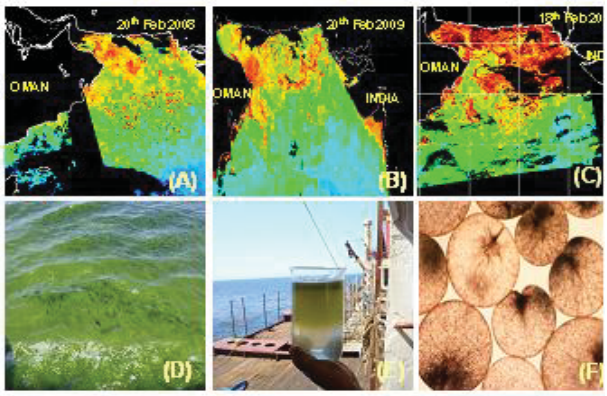
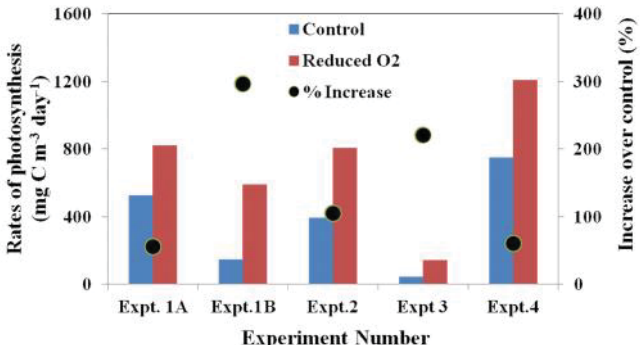


Fig. 1. Spatial extent of *Noctiluca* bloom as seen in Aqua-MODIS daily chlorophyll images of Feb. A) 2008, B) 2009 & C 2010. D) Blooms as seen from the ship-deck. E) Bucket sample transferred to a glass beaker shows thickness of bloom F) Bloom sample under a microscope showing individual *Noctiluca* cells.



If indeed *Noctiluca* benefits from the steady eutrophication of the AS its emergence will impact the food web with significant consequences for ocean biogeochemical cycling and fisheries. The frequencies and extent of coastal hypoxia are increasing (*Diaz & Rosenberg 2008),* and this trend is predicted to persist with future climate change because warming of surface waters could decrease gas solubility, increase organismal metabolic requirements, and surface stratification. The resources of the AS support the livelihood of ~150 million people living along the coasts, and therefore this research is of immense scientific and societal significance. During our 2011 cruise we were able to culture *Noctiluca* which affords us a tremendous opportunity to conduct a variety of laboratory studies. In the proposed study we plan to use our *Noctiluca* culture to investigate the effects of low O_2 on the growth, physiology, and nutritional mode of *Noctiluca*. We aim to better understand whether hypoxia and/or other biological and environmental conditions that develop following the onset of the winter monsoon, either alone or in combination, create a special niche for *Noctiluca* to proliferate to the exclusion of other phytoplankton.