The Arabian Sea: A Natural Experiment in Phytoplankton Biogeography

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LONG-TERM GOALS

My long-term goal is to contribute to our understanding of the way different marine ecosystems function, and to the role of natural selection and micro-evolutionary processes in ecosystem resistance and resilience. In particular, I am interested in the interaction between physical, chemical, and bio-optical properties of the water column and the distribution, productivity, and genetic diversity of different phytoplankton taxa. An underlying premise of my research is that the taxonomic composition of the phytoplankton community has a large effect on the dynamics of the ecosystem, and that a taxon-based approach which considers physiological and genetic factors unique to each taxa is needed to understand and predict changes in ecosystem structure and function.

OBJECTIVES

The objective of this research is to test the general hypothesis that the phytoplankton bloom associated with the Southwest Monsoon in the Arabian Sea is "seeded" by neritic taxa introduced into offshore waters by the general reorganization of currents which accompanies the Southwest Monsoon. Specific hypotheses to be tested were:

1) that major bloom-forming taxa are large diatom and dinoflagellate species typically described as "neritic" taxa adapted to coastal conditions of temperature, water column optics, and nutrient availability.
2) that these taxa go extinct in offshore waters during the Northeast Monsoon, when natural selection favors species more adapted to oceanic conditions,
3) that bloom-forming taxa and coastal forms of marine *Synechococcus* are reintroduced offshore at the beginning of each upwelling period by the general reorganization of currents that occurs during the spring intermonsoon period, and
4) that the dominant taxa are genetically diverse; natural selection will cause a general increase in the frequency of ecotypes adapted to the nutrient regime offshore relative to the frequency of ecotypes adapted to the neritic environment as the monsoon progresses.

APPROACH

I participated in four cruises to the Arabian Sea in 1994-95; each cruise had the goal of describing upper ocean processes in the Arabian Sea and included ten days of SeaSoar operations and ten days occupying stations along the SeaSoar cruise track. Coordinated sampling by all participants produced an extensive data base which includes hydrographic information, nutrient and pigment data, productivity data, bio-optical data and information on DOC concentration. My field program was designed to identify the

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distribution of neritic and oceanic taxa by microscopy and by spectrofluorometric methods. The spectrofluorometric methods were directed toward analysis of the distribution of spectrally distinct forms of chroococcoid marine cyanobacteria (e.g. *Synechococcus* spp.). Chroococcoid marine cyanobacteria contain phycoerythrin (PE), a distinctive and highly fluorescent pigment. Different strains of chroococcoid cyanobacteria produce forms of PE which differ in the relative concentration of two chromophores, phycourobilin (PUB) and phycoerythrobilin (PEB); PEB is always present in the PEs of marine cyanobacteria, but many strains also produce PEs with both chromophore types. PEB absorbs primarily green light (~550 nm) and the presence of PUB greatly enhances absorbance of shorter wavelengths (~500 nm), presumably providing a competitive advantage for strains with PUB in more transparent waters.

Earlier work in the North Atlantic showed that PUB-lacking PEs were associated with continental shelf waters and that the PE fluorescence signature of oceanic waters was dominated by organisms producing PUB-containing PEs (Wood *et al.*, 1998). Fluorescence emission spectroscopy was used to characterize PE types in the North Atlantic; this approach is sensitive to whether or not the dominant PEs contain PUB, but it does not provide any information that can be used to distinguish among PEs with different amounts of PUB. In the Arabian Sea study, I used a combination of fluorescence excitation spectroscopy and fluorescence emission spectroscopy. This is an improvement over the approach used in the North Atlantic study because it provides information on relative chromophore abundance as well as chromophore composition.

The laboratory component of this project involves sample analysis, cultivation of phytoplankton isolates from the Arabian Sea, and investigation of the physiology of the isolates.

RESULTS

Identification of strong coastal filaments and jets that are persistent features off the coast of Oman during the Southwest Monsoon revealed a mechanism for offshore transport of coastal communities of phytoplankton. Samples collected on the continental shelf in upwelling centers were often dominated by nearly monospecific blooms of diatoms, but filament waters that had moved offshore and were composed of a mixture of upwelled and ambient water showed more complex community structure. Large populations of photosynthetic dinoflagellates often coexisted with large populations of diatoms, usually species that were less heavily silicified than those which dominated on the continental shelf. Of considerable interest were the development of blooms of mucilage-producing taxa, both *Thalassiosira* spp. and *Phaeocystis* spp., and the great increase in the concentration of chroococcoid cyanobacteria as upwelled waters moved offshore in the filament. While the abundance of chroococcoid cyanobacteria was low in newly upwelled waters, we observed some of the highest concentrations of *Synechococcus* reported anywhere in the world in upwelling-influenced waters just seaward of the shelf break during the end of the Southwest Monsoon.

PE fluorescence excitation spectra from the Arabian Sea all had either shoulders or peaks at 500 nm, indicating that the PE fluorescence signature was dominated by PEs with PUB. In early June samples from offshore waters had fluorescence excitation spectra characterized by very high amounts of PUB relative to PEB whereas those from upwelling-influenced waters had fluorescence excitation spectra characterized by low amounts of PUB relative to PEB. The low PUB-PEs were also closely associated with a filament of cool upwelling-influenced water. This filament represented an offshore deflection of currents that flow north along the Omani coast and was a persistent feature throughout the Monsoon season of 1995. In September, 1995, PE fluorescence data and *Synechococcus* abundance estimates showed that the total abundance of picocyanobacteria had increased greatly in offshore waters and that low PUB-containing PEs dominated the water column at nearly all sampling locations, both onshore and offshore. This accompanied a progressive decrease in the transparency of the water column, and an increase in the attenuation of blue wavelengths relative to green wavelengths.

Physiological and genetic studies are being conducted with several strains of *Synechococcus* spp. isolated from samples collected in June, 1995. One strain is characterized by large cells, comparable in size and shape to those observed as symbionts in some dinoflagellate species. It appears to have some unusual characteristics with respect to nitrogen utilization and temperature optima for growth.

IMPACT/APPLICATION

Our results show close coherence between the distribution of different taxonomic groups and/or physiological types of organisms and water mass distribution. This suggests that water masses define habitat boundaries and, thus, modern oceanographic techniques can be used to describe the time-rate-of-change of conditions in the water mass. This opens the door to measuring and modeling the selection regime and response to selection by natural populations of phytoplankton and other microorganisms.

Our results also indicate that the optical field itself plays an important role in determining the success of different types of phytoplankton. This is a somewhat novel idea since light quality is not generally viewed as an important niche parameter for marine phytoplankton species.

TRANSITIONS

In collaboration with NRL scientists (Weidemann, Arnone, Johnson, Davis) we recently participated in a cruise off the west Florida continental shelf which will allow us to compare data from our PE characterization of different water masses with *in situ* optical information, SeaWifs imagery, and data collected by aircraft-borne hyperspectral sensors. This will enhance efforts to evaluate optical information inherent in the phycoerythrin signature. In a separate effort, data from our net samples are being used by NRL/SSC scientists (Nielson, Young) to assess the suitability of using bioluminescence kinetic data to discern differences in the community structure of bioluminescent organisms. In connection with this effort, we presented results at the 1998 Ocean Sciences Meeting in San Diego which showed that anomalies in the kinetics of bioluminescence data can be explained by community structure data (See Publications, below).

RELATED PROJECTS

1- Genetic characterization of our Arabian Sea cyanobacterial isolates is being conducted in collaboration with Brian Palenik (Scripps Inst. Oceanography) who has an NSF-funded grant to examine genetic diversity in the marine *Synechococcus.*

2- Net tows we collected were split with Sharon Smith (RSMAS) for use in her NSF-funded study of copepod abundance and productivity during the Southwest Monsoon.

3- Net tows we collected were split with Laurie McDonough, a graduate student at Brown University, and these samples are being used to assess foraminferan diversity and abundance in coastal filaments during the Southwest Monsoon. Ms. McDonough and Dr. Dave Caron (WHOI) are also trying to identify the symbionts associated with the forams using molecular genetic techniques.

PUBLICATIONS

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