Interactions of Small-scale Physical Mixing Processes with the Structural Morphology and Bloom Dynamics of Non-spheroid Diatoms

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Award # N00014960247
http://thalassa.gso.uri.edu/rines
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LONG-TERM GOALS

Our long term goal is to understand the ecology of the large, colonial diatoms which frequently dominate the phytoplankton of coastal shelves, upwelling areas, fjords and banks. We are interested in ways in which species-specific properties, including colony size and shape interact with small scale physical mixing processes to regulate the spatio-temporal distribution of diatoms. We wish to understand these processes in sufficient detail to be able to predict bloom dynamics, size structure and the impact of species-specific characteristics of the phytoplankton on ocean optics.

OBJECTIVES

Our current research addresses the role of shear in regulating diatom blooms. Our goal is to increase understanding of how small-scale physical mixing processes affect the distribution of individual diatom taxa in space and time, as well as potential effects on growth, mortality and the size spectrum of colonies in the ocean. First order questions include (1) What is the pattern of distribution of diatoms in the field in space and time? (2) Do highly stratified regions of the water column provide sufficient refuge from disruption to lead to the formation of phytoplankton layers? (3) What is the relative susceptibility of different diatoms to shear stress? (4) Does a colony's past history affect its susceptibility to breakage? (5) Can diatom mortality be predicted based on larger scale physical forcing factors such as wind speed?

APPROACH

We are investigating biological-physical interactions between diatoms and their environment by means of combined laboratory research and field observations. Last year we concentrated on laboratory experiments, which examined the response of several kinds of diatoms to different levels of turbulence. This year's efforts focused on our field program in East Sound, Washington. We participated in two separate cruises, 27 May - 2 July and 27 July - 14 August. The first was part of the multi-investigator,

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**
4. TITLE AND SUBTITLE **Interactions of Small-scale Physical Mixing Processes with the Structural**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Rhode Island,Graduate School of Oceanography,Narragansett,RI,02882**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **See also ADM002252.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

interdisciplinary Thin-Layers Experiments, and the second was concurrent with the Friday Harbor Ocean Optics course, and the NRL hyperspectral overflights of the region.

Field sampling of phytoplankton was carried out in collaboration with Donaghay's (URI) and Gifford's (URI) programs. On Donaghay's boat, vertical profiles were made at a series of stations around East Sound. Phytoplankton samples were collected from discrete depth intervals with a siphon mounted on his profiling package. Instrumentation measured optical structure (total and dissolved spectral absorption and transmission at 9 channels with a WetLabs ac-9), physical structure (temperature, salinity, density with a SeaBird 9-11plus CTD), current velocities and current shear (with an RDI 1200 khz ADCP) and chemical structure (SeaBird oxygen, pH, Eh probes). Gifford's team worked off the R/V Henderson, moored in the upper sound. Their profiling package provided less physical data, but samples were obtained at higher resolution because of the greater stability of the platform. We also collected surface samples at sets of up to 10 stations throughout the sound. An aliquot of each sample was preserved for later enumeration of cells in the lab. Approximately 750 ml was concentrated, examined live under the microscope, and recorded on videotape, providing both a real-time assessment of the phytoplankton assemblage, and archival images. Standard, 35mm photographs were taken on occasion in order to provide publication-quality images of phytoplankton. Selected photographs were/will be scanned into the computer for use in our web site. A land based weather station recorded wind speed and direction.

WORK COMPLETED

Since our last report, we have replicated previously conducted laboratory experiments, initiated work with a *Thalassiosira* sp., and continued data analysis. We designed and constructed equipment for conducting similar experiments with wild populations in the field. While in East Sound, we:

(1) surveyed the phytoplankton community, compiled a cumulative checklist of all phytoplankton identified to date, and photographed most of the diatoms. This information was put on the web (via Cowles' wireless network) while we were still in East Sound in order to aid Thin-Layers colleagues in the accurate identification of phytoplankton. It is now permanently on line (http://thalassa.gso.uri.edu/ESphyto).

(2) collected and photographed diatom colonies up to 4mm in length, thus demonstrating our ability to handle fragile material in the field. Images of 2 – 4 mm colonies of *Chaetoceros cf. convolutus, Chaetoceros debilis, Chaetoceros radicans* and *Eucampia zodiacus* will soon be on line (http:thalassa.gso.uri.edu/ESphyto/. Choose "Size & Shape in Marine Phytoplankton").

(3) obtained ~6 vertical profiles (with accompanying physical/optical data) of discrete phytoplankton samples through several types of hydrographic regimes. In each case, samples were examined live, in near real-time, and archival videotapes were made for future reference. Aliquots were preserved for quantitative analysis back in the lab.

(4) made two sets of surface transect surveys (~10 stations) in which we collected phytoplankton samples. These can be used as biological tracers of water masses, as part of our observations on the effects of wind-induced turbulence on the surface phytoplankton community, and as ground-truthing

information on species composition and abundance for the hyperspectral overflights conducted by Curtiss Davis (NRL, Washington).

(5) made observations on the surface phytoplankton community before, and after a "wind event" (an increase in wind speed from <2 m/sec to 6-9 m/sec for 6 hours). Initial qualitative observations suggested there was increased breakage of diatoms in the surface layer; archival video images will be analyzed to determine whether observations are statistically significant.

(6) conducted an initial experiment with the field turbulence tanks.

We are presently in the process of analyzing the large amount of material collected in East Sound this summer. We are quantifying phytoplankton cells in the water samples from vertical profiles in order to determine abundance of individual species vs. depth. This information will be used by ourselves, and our colleagues in the Thin Layers group. It will be compared to the physical/optical profiles collected by Donaghay's team, the basin scale circulation and water mass structure studied by Donaghay, Dekshenieks (URI), Osborn (JHU) and Wiedemann (NRL/Stennis), the acoustical signatures documented by Holliday's group (Tracor) and the optical data collected by Wiedemann.

RESULTS

In East Sound, we have documented the species-specific *pattern* of phytoplankton distribution through several types of hydrographic systems, including those with (1) little vertical structure, (2) two-layered structures, and (3) complex (Thin-Layered) structures. On the basis of our real-time, qualitative observations (quantification is in progress), we have learned that well mixed systems with little vertical structure tend to contain a homogeneous phytoplankton flora. Their ecological and optical properties can be hypothesized to reflect the average conditions of the mixed community. At the opposite extreme, complex hydrographic structures may contain entirely different kinds of phytoplankton at different depths, and may shift over distances as small as ~0.5m. Their ecological and optical properties may change depending on the properties of the particular species present in that layer. Comparison of this data with that from the circulation study will allow us to assess the role that horizontal transport of water masses (with entrained phytoplankton populations) plays in creating the observed layered patterns.

Variations in small-scale turbulence and shear within the water column may also influence the vertical distribution of phytoplankton. Qualitative field observations in East Sound (June, 1995) suggested that small-scale turbulence resulting from wind forcing was capable of breaking apart large colonial diatoms, causing a shift in the size spectrum of phytoplankton particles, changes in dissolved and particulate optical signatures, and potentially altering the species-composition of the phytoplankton through selective mortality of some taxa. We hypothesized that interaction between small-scale turbulence induced by wind- or tidal-forcing and species-specific properties of the phytoplankton is a *process* which might influence the *patterns* of phytoplankton distribution.

Our laboratory experiments support this hypothesis, by demonstrating that turbulence *is* capable of fragmenting colonial diatoms. The degree of damage is related to the silicate concentration of the water. Colonies which have grown in high silicate regimes (e.g. 100 µM) are mechanically stronger that those grown in low silicate conditions (e.g. 10 µM). We have tested five species of diatoms, and they have shown differential susceptibility to damage from turbulence. *Chaetoceros vanheurckii* was most severely impacted. Colonies broke into shorter pieces, and many cells ruptured and died. The genus *Chaetoceros* is a common component of coastal phytoplankton; we have recorded approximately 25 species in East Sound (http://thalassa.gso.uri.edu/ESphyto/list/ppllist.htm). *Chaetoceros vanheurckii* is of representative morphology, and was among taxa which appeared to be broken in the 1995 field event. This years' field observations on a mixed *Chaetoceros* and *Eucampia* community in the surface layer of East Sound suggested a similar response, and it will be exciting to see if our quantitative analysis of the videotapes statistically supports this. If so, it suggests that turbulence resulting from wind-forcing may contribute to Thin-Layer formation by destroying colonial diatoms in surface waters, leaving an intact population at depth.

IMPACT/APPLICATIONS

Our research in phytoplankton ecology and oceanography is based on documentation of *patterns* observed in the field, and investigation of *processes* hypothesized to produce those patterns. It is predicated on the assumption that individual species have unique sets of properties, thus *processes* may act upon them in different ways. Species-specific differences in size, shape and physiology may influence both their functional role in the ecosystem and their optical characteristics. While some kinds of phytoplankton live as single cells, many form multi-cell colonies of millimeter to centimeter scale, which may assume a diverse range of size and shapes. They absorb and scatter light, and release dissolved organic substances into the surrounding water. Since phytoplankton provide food for zooplankton and some kinds of fish (both of which are acoustical scatters), they may affect the distribution of these animals as well. Thus, species-specific properties of phytoplankton, as well as their abundance and distribution in time and space affect both the optical and acoustical properties of the upper ocean environment.

In classic models of phytoplankton ecology, blooms occur when the upper part of the ocean becomes stratified so that cells are retained in the euphotic zone. If the region above the pycnocline remains mixed, the phytoplankton may be expected to be homogeneously distributed. When they exhaust their nutrient supply, senescent cells sink through the water column and accumulate at the pycnocline. Thus, a sub-surface chlorophyll maximum (layer) might simply represent an enhanced concentration of a phytoplankton community which is otherwise homogeneous throughout the water column. Vertical processes have been well studied, and it is clear that they occur in the ocean over some time scale. Two-dimensional, Vertical Ocean models are most applicable to areas where there is low horizontal variability, such as the open ocean. However, in coastal areas where there may be a high degree of horizontal variability, three-dimensional models may be more appropriate. The role horizontal processes play in creating observed patterns has received less attention, in part because new instrumentation and deployment methodologies have been required in order to make the requisite observations. Horizontal processes may operate over much shorter time frames (e.g. tidal cycles, wind shifts), and may result in more complex hydrographic and biological structures. Donaghay's team is especially interested in the role that horizontal processes related to current shear and fine scale stratification play in the formation, maintenance and destruction of Thin Layers. If at least some Thin Layers of phytoplankton are formed as a result of biological-physical interactions between cells and colonies, current shear and fine scale stratification, then species-specific responses to physical properties of the water, in particular the degree of turbulence generated by wind-forcing or current shear may be critical to understanding distributional patterns. Further description of pattern and study of process are critical if we are to understand and predict ecosystem responses, and the related optical and acoustical signatures of interest to the Navy.

TRANSITIONS

Basic information on the diatoms (and some dinoflagellates) found in East Sound is available on the web at http://thalassa.gso.uri.edu/Esphyto. The goals of this web site are: (1) to provide a checklist of taxa we have identified in the San Juan Islands over the last several years, based on approximately 23 weeks of observations (2) to provide photographs and reference materials to aid others in their accurate identification, and (3) to introduce those not familiar with the microscopic world to the diversity of organisms which can be found there.

RELATED PROJECTS

This project is closely tied to Donaghay's core program. We directly benefit from the physical and optical data collected, as well as from use of boat time. We also benefit from information on basin-wide circulation in East Sound collected by Donaghay, Dekshenieks, Osborn and Wiedemann. Our phytoplankton data can in turn be used by them as biological tracers of water masses. It will also be used by Holliday et al. to examine the degree of overlap between layers of phytoplankton and layers of zooplankton, and by Wiedemann to examine the relationship between species-specific distributions of phytoplankton and optical scattering. We also interact with other participants in the Thin Layers Experiments, including Alldredge (UCSB), Cowles (OSU), Gifford (URI), MacIntyre (UCSB), Perry (UW), Smith (URI) and Zaneveld (OSU).

The phytoplankton samples we have collected for examination of diatoms are also being analyzed for several dinoflagellates. This data will be used by Mr. J.M. Sullivan (URI) in his dissertation, which investigates the effect of small-scale turbulence on selected dinoflagellates.