

THE RELATIONSHIP BETWEEN THE FINE-SCALE VERTICAL DISTRIBUTIONS OF MACROZOOPLANKTON, MARINE SNOW, AND TURBULENCE IN THE UPPER WATER COLUMN

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N00014-97-1-0798

LONG TERM GOALS

Recent evidence indicates that large detrital aggregates, known as marine snow, are highly concentrated at pycnoclines and other density discontinuities in the water column due to turbulence, shear, and reduced sinking rates as the particles encounter denser fluid. The consequences of these thin layers of high particle abundance to the fine scale vertical distributions of zooplankton, many of which are voracious consumers of marine snow, is presently unknown, but likely to be significant. Our long term goal is to develop a predictive understanding of the relationship between the vertical distributions of zooplankton, marine snow, and turbulence in the ocean and the impacts of their patchy distribution in thin layers on optical and acoustical properties of the water column.

OBJECTIVES

We focused on 3 scientific objectives as follows: 1) determine whether zooplankton occur at higher concentrations within thin layers of marine snow in nature and, if so, identify the taxa involved, 2) estimate the time scale on which thin layers of marine snow and their associated zooplankton communities persist and 3) examine the significance of physical processes, especially turbulence, in generating or dissipating thin layers of marine snow and zooplankton.

APPROACH

We simultaneously measured the vertical distribution of marine snow, turbulent intensities (measured as the rate of turbulent kinetic energy dissipation, ϵ), and zooplankton abundance and composition in the upper 30 m of the water column. We used real-time measurements of turbulence and stratification in the water column and

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 30 SEP 1997		2. REPORT TYPE		3. DATES COVERED 00-00-1997 to 00-00-1997	
4. TITLE AND SUBTITLE The Relationship Between the Fine-scale Vertical Distributions of Macrozooplankton, Marine Snow, and Turbulences in the Upper Water Column				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 California at Santa Barbara, Department of Ecology, Evolution, and Marine Biology, Santa Barbara, CA, 93106				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					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 4	19a. NAME OF RESPONSIBLE PERSON
a REPORT unclassified	b ABSTRACT unclassified	c THIS PAGE unclassified			

simultaneous visual observations of marine snow distributions *in situ* to guide sampling for zooplankton in 0.5 m layers using diver-towed nets. Marine snow abundance was determined by computerized image analysis of particles from profiles obtained with an *in situ* camera system (MacIntyre et al., 1995). Profiles of energy dissipation rate, length and velocity scales of turbulence, and rates of turbulent mixing were obtained with microstructure profilers built by Precision Measurement Engineering.

WORK COMPLETED

We previously completed two extensive field studies and have spent the second year of this grant focusing on data analysis. First, in May, 1996 we collaborated with several other ONR P.I.'s (Cowles, Donaghay, Zaneveld, Rhines, Holiday) in a 10 day study of thin layers in East Sound, Washington. Our data on microstructure and the distribution of zooplankton and marine snow was complemented by extensive data on the optical, acoustical, chemical, and physical structure of the water column gathered by our collaborators. This study included one 24 hour period during which extensive sampling occurred nearly continuously for most measured parameters. We have counted all zooplankton samples and completed all image analysis and graphical presentation of all marine snow profiles obtained during this study. We have analyzed 65 profiles of energy dissipation rates selected from the several hundred profiles collected in order to provide maximum information for initial interpretation of important mixing and turbulence events.

Second, in June, 1996 we piggy-backed on a 10 day NSF- sponsored cruise in the Santa Barbara Channel, during which time we obtained simultaneous data both day and night on microstructure, marine snow and zooplankton distributions at 8 stations. We have now analyzed all the zooplankton samples and marine snow profiles at this site and over 20% of the extensive microstructure data set collected.

RESULTS

A persistent layer of abundant marine snow composed primarily of chain-forming diatoms and mucus was observed in East Sound. The layer was approximately 1 m in thickness and was located at the pycnocline. The cumulative volume of aggregates within the layer was over 100 times higher than that found elsewhere in the water column and mean aggregate size within the layer increased by a factor of 10. The interstices of diatom aggregates are rich in gel-like exopolymers exuded by the diatoms. Highly porous diatom aggregates containing as little as 0.5-2% gel-like mucus by volume could become neutrally buoyant if they sink into water of only slightly higher salinity because the gel resists salt exchange (Alldredge and Crocker, 1995). The thin-layer of marine snow observed in East Sound was most likely formed by the attainment of neutral buoyancy by sinking aggregates as the dense diatom bloom at the surface aggregated. The position and persistence of the thin layer of marine snow appears to have affected the distribution of other biological and chemical layers in the water column. This hypothesis is consistent with observations of similar thin layers in the Adriatic Sea.

With the exception of polychaete larvae, which were associated with the layer, most major zooplankton taxa (sampled with nets) including copepods, medusae, cyprids, ctenophores and siphonophores avoided the layer. This is consistent with findings of our colleague, Van Holliday, who acoustically measured a persistent thin layer of zooplankton directly below the marine snow layer. Mucus within diatom marine snow has been shown to adhere to zooplankton feeding appendages (Alldredge, unpublished) and zooplankton may have avoided the marine snow layer if it inhibited their feeding efficiency.

More than one mechanism may have been operating to form thin layers of particles in East Sound. Profiles of temperature-gradient microstructure taken every 10 minutes over the tidal cycle, showed that turbulence in the 30 m water column was strongly layered, with layers ranging from 0.1 m to 0.5 m thickness. While turbulence in most layers tended to be moderate to low ($< 10^{-7} \text{ m}^2 \text{ s}^{-3}$), values occasionally exceeded $10^{-6} \text{ m}^2 \text{ s}^{-3}$, in particular near the surface, near the benthic boundary layer, in association with 10 cm scale thermal inversions as would be formed when shear interacts with stratified water, and in association with layers of warm or cold water likely to be indicative of intrusions. Turbulence was damped within the upper layer of marine snow, with rates of energy dissipation at the boundaries insufficient to cause appreciable particle flux. Layers of marine snow comprised of smaller particles were found deeper in the water column. These layers were associated with density discontinuities or thermal inversions. Turbulence was more often damped at the particle maximum and several orders of magnitude larger above and below the aggregate peak. These data indicate that formation of the abundance peaks was caused by a variety of mechanisms. These include reduction of sinking speed as aggregates sink into waters of higher density, with this mechanism being important for the large aggregates within the strongly stratified near surface waters, and, in at least one case, particle disaggregation where turbulence was high at the abundance maximum. Low levels of turbulence within a marine snow layer could indicate that a larger patch was stretched by a shear layer in which the shear was insufficient to generate turbulence. However, in most cases below the surface pycnocline, abundance maxima were associated with intrusions of warmer or cooler water bounded by turbulence.

IMPACTS

Accumulations of marine aggregates in thin layers at the concentrations observed in East Sound are likely to significantly impact the optical properties of the water. Moreover, the avoidance of some thin layers by zooplankton will alter the distributions, behavior, community structure, feeding biology, life history strategies and predator-prey interactions of zooplankton, as well as the optical and acoustical properties of the water column. Our coupled physical and biological studies will help determine how long these layers persist and increase our understanding of the mechanisms forming them.

TRANSITIONS

Future research on thin-layers in East Sound will incorporate the possible detection of these layers with remote sensing. The existence of thin-layers may significantly alter remotely sensed data if they can be detected with these tools.

RELATED PROJECTS

This project was developed from discoveries made regarding the aggregation and distribution of marine particles in the now completed SIGMA (Significant Interactions Governing Marine Aggregation) ARI. Portions of this research were done in collaboration with ONR P.I.s Tim Cowles, Russ Desiderio, and Ronald Zaneveld of Oregon State University, Percy Donaghay and Jan Rhines of the University of Rhode Island, and Van Holliday of Tracor Applied Sciences. This group plans to continue investigation of the persistence of thin layers and the mechanisms which form them. A special session on our joint results will be presented at the AGU/ASLO Ocean Sciences meeting in February, 1998 and numerous manuscripts are in preparation.

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