

Acoustical Technology for the Study of Marine Organisms

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LONG-TERM GOAL

The long-term goal of our joint research program is the development of data-based models to predict ecological relationships of plants and animals to the physical and chemical environment in the sea.

OBJECTIVES

Chronic undersampling of the marine environment, including both biological and physical components has been and remains, a major block to understanding how marine ecosystems function and how they respond to changes, whether natural or anthropogenic. Consequently, data-based models that predict local abundances of plant and animal life in the sea are rare or do not exist at all. Such models would be invaluable in predicting variables such as acoustical and optical scattering in areas of tactical interest to the Navy. Our research directly addresses the root of this problem by attempting to advance acoustical technology as an aid in measuring spatio-temporal distributions of a variety of marine organisms in relation to the physio-chemical ocean environment.

APPROACH

There are multiple objectives for this program of research. The first involves Tracor's participation in a multi-investigator experiment that was designed to examine and quantify the characteristics of a phenomenon that we are generically calling "thin layers". We believe this phenomena, which has been observed in a number of littoral environments, may play an important role in the functioning of coastal marine ecosystems. Retrospective examination of coastal ocean data for such structures has revealed their presence in a variety of locations, but only recently have improvements in the spatial resolution of a variety of optical and acoustical sensors allowed us to accurately estimate the scattering intensity from, or the percentage of the water column biomass which occupies, these small scale vertical structures. Our high resolution, high frequency acoustical instruments were employed to examine the zooplankton response to optically detected phytoplankton layers (~10 cm thickness) and to direct conventional sampling devices (pumps and siphons) to those layers in order to examine their constituent parts.

The second element of our research, to be addressed during the last half of this three-year project, involves investigation of a new acoustical method for studying organisms in aquatic ecosystems. Over several years, we have successfully exploited the spectral frequency dependence of acoustical

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backscattering on the size and abundance of water column zooplankton, micronekton and fish. The multi-frequency methods we have developed are now being used by a substantial number of investigators in fields ranging from fisheries to biological oceanography. We have also just begun to apply them to the examination of the benthos. While we are convinced that there remains much to be gained by the further development of bioacoustics in the spectral domain, we believe that it is time to open an additional dimension to exploitation -- that dimension is the 3-D multi-static, azimuthal dependence of scattering from marine organisms. This work will also encompass investigations of new approaches to the generic inverse problem for bioacoustics, some of which may be applicable to problems in classification and identification, both for biotic and abiotic acoustic targets.

WORK COMPLETED

An ONR-sponsored, multi-institution, multi-investigator field experiment directed at an examination of thin layers of marine organisms, the processes that cause their formation and dissipation, and their impact on ocean optics, ocean acoustics and the ecosystem, was carried out in East Sound, Orcas Island, WA during June, July and August 1998. In early June, we moored three uplooking Tracor Acoustic Profiling Systems (TAPS) in mid-water at a depth of ca 12 m in a small, shallow fjord in the San Juan Islands in Washington State. Each of these TAPS sensors, spaced at the corners of a triangular array with sides of about 300 m length, measured acoustical scattering at 12.5 cm depth intervals from just above the sensors to the surface. Ensemble averages (24 echo ranging cycles) of volume scattering strength at six discrete frequencies were reported from each instrument at one minute intervals. The data were transmitted to a shore station via underwater cables, where they were recorded and then transmitted to an OSU ftp site several km away on the western side of East Sound. The data could then be accessed by other scientists participating in the experiment, including those doing broad scale surveys in the sound from small craft, and by those doing detailed direct sampling and in-situ observations from the R/V Henderson, which was moored near the western side of the TAPS array. Our real-time monitoring of zooplankton layers, fluorescence, and the physical environment at the Henderson and at the nearby TAPS array, allowed our co-PIs aboard the Henderson to collect water and organisms from these very thin (sub-meter) layers for a wide variety of experiments.

Aboard the Henderson, Tracor also deployed an eight-frequency TAPS in a cast mode. This sensor was used to fine-tune the directed sampling efforts and to estimate the size spectra of the zooplankton in the thin layers. We also recorded wind speed and direction, surface conditions, and ambient irradiance. A simple underwater camera and sensors for measuring conductivity, temperature and downwelling light were deployed with the eight-frequency TAPS in a cast mode from the Henderson, both on a tidally synchronized cycle and on demand, as desired by other investigators on board. Samples were also collected to define the physio-chemical and optical environments. The URI team also moored profiling sensors near the corners of the TAPS array to measure water column optical, physical and chemical properties, and turbulence.

After the research team on the Henderson completed the on-site measurements and departed (at the end of June), we continued to remotely operate the moored array of TAPS (through mid-August). In addition to recording data from each array at the shore station and on the OSU ftp site, we were able to download the data daily from a variety of remote locations from our home laboratory and as we traveled around the US on other business. Scientists from NRL/DC were conducting hyperspectral optics overflights in an area that included our TAPS array during early August. Having the data

accessible via the Internet allowed us to provide the scientists supporting these experiments on Orcas with twice daily updates on the presence and characteristics of thin layers and other interesting scattering structures at the array without our being "on-site".

We have collated the data we collected at East Sound, and have distributed it to our co-principal investigators on CD-ROMs and in a notebook format.

RESULTS

We have only just begun to examine the immense data set collected during the "thin layers" project. Taken as a whole, that data set is clearly the largest and most comprehensive such data set of its kind. A cursory examination of our own data reveals numerous small-scale structures in the vertical dimension, including sub-meter thick optical and acoustical layers. These layers were at the same time dynamic, and persistent. We also observed strong scattering near the top of the water column, which appeared to be associated with Langmuir circulation at wind speeds that were well below those that would create breaking waves. The usual increases in surface scattering due to the mixing of bubbles into the water column were also observed when whitecaps were present. We observed the diel formation and dispersal of schools of juvenile herring. There were also preliminary indications that there was a correlation of bioluminescence, as measured by UC Santa Barbara scientists and acoustical scattering as measured by our multi-frequency acoustical sensors. We observed scattering from organisms in the water column that could be explained by observed distributions of the naked dinoflagellate, *Nocticula scintillans*, but have not yet had an opportunity to rule out the co-occurrence of other organisms of the same sizes, based on our net, pump and bottle collections.

As planned, the principal emphasis of our work has involved the design and implementation of a project to study thin layers and associated processes. We anticipate that while we process and interpret the data from East Sound over the next few months, the work on exploitation of azimuthal dependencies in scattering from zooplankters will be restricted to the detailed design of the instrumentation to be used during the last half of our funding period, and to the development of a bit of theory that will be needed when we obtain multistatic data on azimuthal scattering from simple shapes.

IMPACT/APPLICATION

Observation of aquatic animals in their natural environments remains a major challenge in both biological oceanography and limnology. Critical processes in feeding, reproduction, growth and predation in small zooplankton occur at scales from fractions of millimeters up to scales which match the ambits of individuals. It is often difficult to reproduce all essential features of the marine environment in the lab, where observation of small scale processes is more tractable than at sea. Therefore, there is continuing interest in improving our ability to observe and quantify *in situ* spatial and temporal changes in the distribution and abundance of zooplankton in relation to natural physical, chemical and other biological fields.

A substantial amount of the zooplankton biomass can be concentrated in heterogeneous, small scale structures, one form of which is a very thin layer (Donaghay, *et al*, 1992; Cowles and Desiderio, 1993; Donaghay and Osborn. 1997). Thin layers are known to impact both optical and acoustical properties of the water column. The biological and physical reasons for this distribution are poorly understood, but it

is clear that this kind of distribution is neither unusual, nor rare, in coastal regions. This kind of distribution clearly has implications for predation by larger animals, e.g., for larval and juvenile fish. Its causes may be rooted in distributions of food, i.e., phytoplankton, but may also be at least in part physically driven (e.g., the advantages of moderate levels of turbulence are discussed by Rothschild and Osborn, 1988).

Understanding the distributions of small scale structures, their patterns and the processes that lead to their formation and dissolution must precede modeling and prediction of their occurrence and subsequent impacts on underwater visibility, water column optical properties and underwater acoustical scattering.

TRANSITIONS

During the last decade, we have developed a variety of new multi-frequency acoustical technologies for use by fisheries scientists and biological oceanographers. Our participation in the thin layers field work and in the on-going data synthesis with the "thin layers" principal investigators is a part of our continuing education program in the use of these new methods. Direct participation in such programs is intended to assure a transition of these technologies to a broad range of scientists working with zooplankton in marine and limnological ecosystems.

RELATED PROJECTS

The "thin layers" project is a cooperative research effort involving scientists from Tracor (Holliday, Greenlaw, McGehee), the University of Rhode Island (Donaghay, Rines, Deksheniaks, Gifford, Smith), Johns Hopkins University (Osborn), Oregon State University (Cowles, Sullivan, Zaneveld), the University of Washington (Perry), the Naval Research Laboratory / Stennis Space Center (Weidemann), the University of Southern California (Pieper), and the University of California at Santa Barbara (Aldredge, MacIntyre, Case/Herron).

REFERENCES

Rothschild, B.J. and T.R. Osborn. 1988. Small-scale turbulence and planktonic contact rates. *J. Plankton Res.* 10: 465 - 474.

Donaghay, P. L., H. M. Rines and J. M. Sieburth, 1992. Simultaneous sampling of fine scale biological, chemical and physical structure in stratified waters. *Arch. Hydrobiol.* 36:1-14

Cowles, T. J. and R. A. Desiderio, 1993. Resolution of biological microstructure through in situ fluorescence emission spectra. *Oceanography* 6(3): 105-111.

Donaghay, P. L. and T. R. Osborn. 1997. Toward a Theory of Biological-Physical Control of Harmful Algal Bloom Dynamics and Impacts, *Limnol. Oceanogr.* 42: 1283-1296.

PUBLICATIONS

Barans, C.A., B.W. Stender, D.V. Holliday and C.F. Greenlaw. 1997. "Variation in the vertical distribution of zooplankton and fine particles in an estuarine inlet in South Carolina", *Estuaries* 20(3): 467-482.

Holliday, D.V., R.E. Pieper, C.F. Greenlaw and J.K. Dawson. 1998. "Acoustical Sensing of Small Scale Vertical Structures in Zooplankton", *Oceanography* [in press].