GLOBEC

Global Ocean Ecosystems Dynamics

A Component of the U.S. Global Change Research Program

GLOBEC Workshop on Acoustical Technology and the Integration of Acoustical and Optical Sampling Methods

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The Editorial Committee for this workshop report included Chuck Greene, Charles Greenlaw, Van Holliday, Peter Ortner, Rick Pieper, Tim Stanton and Jim Traynor.

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Executive Summary

Changes in global climate, whether from anthropogenic or natural causes, will produce changes in the ocean environment. One of the primary objectives of GLOBEC is to assess the ultimate predictability of the response of life in the sea to changes in ocean physics. Understanding the mechanisms and processes that relate an animal's ability to survive and reproduce to the ocean's dynamic environment are essential to the success of GLOBEC. Understanding these complex interactions will require the advancement of technology on a variety of fronts. Ready access to conventional oceanographic technology, as well as the development of new instrumentation and methodology, is required to achieve GLOBEC's objectives.

The GLOBEC science community is interdisciplinary. It includes a diverse group of technologists who develop instrumentation that biological oceanographers, physical oceanographers, and mathematical modelers will use in the design and interpretation of experiments. This integration of technologists and scientists provides the means for effectively studying and understanding the structure and dynamics of marine ecosystems. Establishment of a coherent approach for use in addressing GLOBEC science issues, especially to quantify the physical environment and the relation of ocean physics to the animals that live in the sea, is a continuing concern in GLOBEC.

To facilitate achieving the goals of GLOBEC, a coherent approach to GLOBEC related studies is advised. To enhance communication and cooperation between scientists, the GLOBEC Steering Committee is sponsoring a series of focused, interdisciplinary workshops that address the role of advanced technology in the GLOBEC program. In this context, over 50 biological and physical oceanographers, fisheries scientists, mathematical modelers, physicists, and engineers met at NOAA/NMFS and WHOI in Woods Hole, MA in April 1991 to discuss the existing capabilities and potential developments in acoustical and optical technology, methodology, and instrumentation for measuring spatial and temporal distributions and assessing the behavior of animals in the sea.

The group identified a variety of acoustical and optical instruments and techniques that can be used in pursuit of GLOBEC's science objectives. It was determined that the integration of acoustical and optical technology would be highly beneficial and that the technologies were both complementary and synergistic in their potential utility. Synoptic sampling of both the biological and physical characteristics of the water column was stressed. Sensors which operate on quasi-continuous spatial and temporal scales were viewed as essential if GLOBEC is to link small scale process measurements to population parameters. The importance of quickly establishing a definition of data archiving and retrieval protocols for GLOBEC was recognized. Several methods for enhancing an individual investigator's access to complex acoustical and optical instruments were examined. Similarities were identified in the acoustical technologies used to examine zooplankton, micronekton, macroplankton, and fish, but it was recognized that system parameters (e.g., operating frequencies, beamwidths, signal and data processing algorithms) are often so different that alternate implementations of the same basic technologies may be necessary to examine different elements of the food web. An emphasis on the acquisition, integrated processing, and display of multifrequency acoustic data was a recurring theme in working groups dealing with different trophic levels. Specific requirements for new research regarding the synthesis and display of multifrequency data sets were identified. Calls for new research also included the advancement of theory and supporting measurements in describing scattering from individual organisms and the development and validation of methods for quantitative fusion of multisensor data.

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1. Introduction

1.1 Background

a. What is GLOBEC?

GLOBEC (GLOBal Ocean ECosystems Dynamics) is a science component of the U.S. Global Change Research Program. Planning efforts for the U.S. component of the GLOBEC research initiative are sponsored by NSF with NOAA and ONR participation. The GLOBEC concept involves gaining an understanding of how physical processes, both direct and indirect, influence the success of individual animals in the sea through their feeding, reproduction, and survivorship. GLOBEC also addresses relationships between the success of the individual and the dynamics of the population. Additional information on GLOBEC can be obtained by requesting the U.S. GLOBEC Report Series from JOI, Inc. (1755 Massachusetts Avenue, NW, Suite 800, Washington, DC 20036-2102). A list of the reports that are currently available are included in the References.

b. Steering Committee Function and Objectives

The U.S. GLOBEC Steering Committee was established to plan, promote, and coordinate the physical sciences-biological sciences partnership needed to assess the consequences of changing global climate on marine animal production. The current membership of the Steering Committee is provided in Appendix A. One goal of the Steering Committee is to provide an assessment of the current and future availability of appropriate technology to groups planning the science components of GLOBEC. Specifically, there is a need to describe the research, development, organization, and resources needed to make advanced technology available to assist the community in reaching GLOBEC's science goals. It is also timely to provide the interested funding agencies with the science and technology community's view of the potential, cost, and time required to develop or acquire candidate instrumentation and technology in support of the GLOBEC effort.

c. The Role of New Measurement Technology

The Steering Committee for the U.S component of GLOBEC is attempting to anticipate and describe the necessary technological tools and advances for support of the GLOBEC research initiative during the 1990's.

It is anticipated that substantial progress will arise from the development and application of new technologies for sampling of both the biota and the physical environment. Additional advancements are expected from the interactive collaboration of physical oceanographers, technologists, and biological oceanographers, as well as from the stimulation and opportunities that the GLOBEC initiative provides to investigators in the ocean sciences community. One of the keys to advancing our understanding of the relationship between ocean physics and the distributions of animals in the sea is the rapid, simultaneous measurement of each. Given the potential gains in understanding ocean ecosystem dynamics through application of new technology, it is evident that timely development of necessary sampling technology and measurement tools is of critical importance to GLOBEC.

Underwater acoustics and underwater optics appear to be appropriate tools for quantitative assessment of fish and zooplankton. Additionally, simultaneous and complementary uses of acoustical and optical technology may bring advantages to both disciplines. In support of the GLOBEC science planning activities, a Workshop on Acoustical Technology and the Integration of Acoustical and Optical Sampling Methods was held in Woods Hole, Massachusetts on April 2-4, 1991. The Woods Hole Oceanographic Institution and the NOAA National Marine Fisheries Service, Northeast Fisheries Center were hosts for the meeting. This report attempts to document the key findings of the workshop participants.

1.2 Objectives of the Workshop

Fisheries acoustics is relatively advanced compared to the state of the development of acoustic technology for studying micronekton and macrozooplankton. The use of acoustics for studying small zooplankton is also relatively new and the joint use of acoustics and optics is an unexplored area. It was recognized that, since the different working groups were dealing with disciplines which varied in their maturity, not all of the issues would be appropriate for each group. Consequently, the order and priority in which issues were addressed was left to each group.

The following issues and challenges were identified as being of interest to the GLOBEC Steering Committee.

- The issues of priority, protocol, cost, and time frame for instrument acquisition and technology development need to be addressed in 3 categories: 1) off-the-shelf instrumentation; 2) modification or adaptation of off-the-shelf gear at moderate cost; and 3) critical new research or development focuses for instrumentation or methodology.

- Development of a protocol for instrument calibration to ensure valid comparisons of measurement results among different geographic areas, times, projects, and investigators.

- Protocols within which unique or complex instruments can be accessed by investigators within the GLOBEC community, and definition of a route to the development and construction of an infrastructure for GLOBEC that will assure and support such access.

- The role of acoustical and optical technology in quantifying and linking different scales of measurement in time and space for GLOBEC.

- As appropriate for each working group, recommendations for "calls for proposals" in specific areas of acoustical and acoustical/optical technology which should be considered by the GLOBEC Steering Committee and possibly to be forwarded by that group to appropriate funding agencies.

- Any other areas in acoustics, optics, and the integration of those two disciplines that the working groups might deem critical or important in preparing the science and technology communities to address GLOBEC science issues.

As one examines the individual working group reports, it will be evident that some issues were considered to have a higher priority than others. Some issues were addressed in detail and others were only discussed briefly or not at all. It should be noted that the time constraint of a little more than one day for working group meetings precluded addressing all issues in equal detail.

1.3 Workshop Organization

To achieve an adequate representation of the technical disciplines needed to address GLOBEC's acoustical and optical technology requirements meant bringing together biological oceanographers, fisheries scientists, physical oceanographers, mathematical modelers, physicists, electrical engineers, and a variety of other technical specialties (see Appendix B for list of workshop participants). A small, informal poll of the invitees, before the workshop convened, revealed that individual participants knew a third or fewer of the other workshop attendees. The success of such interdisciplinary meetings is often the clear definition of the common problem to be addressed. To provide a common starting base, one-half of the first day was dedicated to definition of GLOBEC and a description of the science problems and environments of interest to potential GLOBEC investigators. The second half of the first day included several presentations that reviewed the history and the state-of-the-art in the acoustical and optical technologies on which GLOBEC technologists will likely draw in developing instrumentation and methodology. In recognition of the diverse backgrounds of the workshop participants, the speakers attempted to emphasize concepts, general methods, and results rather than technical detail.

On the morning of the first day a description of the developing GLOBEC science focus and of several GLOBEC field programs under discussion for the 1990's was presented (see Appendix C- Meeting Agenda). These presentations provided examples of the science issues related to GLOBEC that would benefit from the application of existing, modified, and/or new acoustic technology as it impacts our ability to understand the dynamics of typical ocean ecosystems. They also provided an indication of the range of ocean environments that may be encountered in GLOBEC studies. The ocean environment is often a limiting factor in the performance of acoustic and optical instrumentation.

The afternoon of the first day was dedicated to review and survey papers by investigators who are active in four related research areas: 1) fisheries acoustics; 2) mesopelagic fish acoustics; 3) euphausiid (krill) acoustics; and 4) zooplankton acoustics.

On the second day, several working groups were convened. Three of these strived to identify applicable acoustic instrumentation and technologies in historically distinct, but overlapping bioacoustic disciplines of: fisheries acoustics, micronekton/macro-zooplankton acoustics, and small zooplankton acoustics. A fourth working group focused on the possible integration of acoustical and optical techniques. The groups were asked to address the following: the availability of off-the-shelf instrumentation; existing instrumentation that could be modified quickly and at moderate cost; existing technology that is not yet widely available, but could be made so in the time-frame of GLOBEC; and new concepts that could have a major impact on the science in the 1990's if the necessary resources were made available for research and development.

Applicable technology and methods as well as instruments were identified. In areas where a consensus evolved from the deliberations, general priorities for funding of instrument acquisition as well as research and development were recommended. Ways to increase the availability of necessary instrumentation to all GLOBEC investigators were also solicited. For example, in some cases, acquisition of low cost instruments by individual investigators, or small groups, within the context of their science proposals may be most appropriate. In other cases, the acquisition of unique or high-cost instruments or facilities by larger coalitions of scientists interested in providing a service to the community may be the most practical approach. Following brief meetings of the working groups, a panel discussion of mechanisms for developing educational and training opportunities for undergraduates, graduate students, and postdoctoral scientists opened the plenary session on the third morning. The workshop concluded at noon with presentations by the working group chairmen summarizing the findings of each group. The Editorial Committee (see inside cover) then turned its attention to the integration of the separate working group reports into a compatible format.

Working groups were organized within traditional acoustic subject divisions rather than those possibly more common to the biological disciplines. The acoustical method of grouping the organisms that live in the sea is largely based on size, numbers/m^3, and to some degree, their behavior, environment, and distribution. These are all important parameters in determining the acoustic methods and operating parameters to be used for detecting and quantifying distribution, abundance, and characteristics of the animals. Both the acoustical and the biological method of grouping subjects is somewhat artificial. There is often overlap in the types of acoustic technology used to examine the range of sizes between egg and adult life stages, and interactions between trophic levels in the food web. Likewise, the complexity of the marine food web makes it difficult to examine any individual species or group in total isolation.

The fisheries acoustics group dealt principally with adult nekton. The micronekton/macroplankton group included scientists with interests in juvenile and larval fishes, myctophids, euphausiids, and large zooplankton. In general, these animals are complex scatterers of sound, requiring application of either very simple (e.g., empirical regression models) or reasonably complex mathematical formulations (e.g., rough, bent cylinder scattering models) to describe their acoustic reflectivities. While improvements in scattering models applicable to small zooplankton will probably be a natural outcome of continued work on those organisms, variations on the fluid sphere model have been used with some success since 1950 (Anderson, 1950) to describe the acoustic reflectivity of small crustaceans such as copepods. The original division of the micronekton/macroplankton group and the small zooplankton group was based on the type of scattering model that might be most appropriate to describe the scattering from the target organisms. Subsequently, the working group dealing with small zooplankton decided that, in view of the range of capabilities of the technologies under discussion in the group, they should also consider organisms at least as large as the smaller euphausiids. The group charged with examining the potential for integrating acoustical and optical sampling technologies dealt with all sizes and genera for which those techniques appeared to be appropriate.

2. Fisheries Acoustics

Chair: Jim Traynor
Rapporteur: Gordie Swartzman

Participants: Lee Culver, Steve Brandt, Len Zedel, John Simmonds, Ken Foote, Steve Clark, Pat Twohig, Charles Thompson, Bill Michaels, Janusz Burczynski

2.1 Scientific Context

The Fisheries Acoustics Working Group addressed how fisheries acoustics techniques can be applied to answer questions important to accomplishing GLOBEC objectives. The list below includes the questions posed and potential acoustic techniques for addressing these questions.

Does a change in ocean environment result in a change in fish distribution and migration?

Echo integration was considered the most important technique for studying fish distribution. For fish distribution studies near physical phenomena such as ocean fronts, vessel surveys must extend over sufficient distances to describe the distributional (vertical and horizontal) characteristics at an appropriate scale to characterize each environment. To facilitate scaling of echo integration information, target strength data should be collected when possible. The group felt that, in most marine situations, it is dangerous to scale echo integration results by simultaneously collected target strength data because of limitations in target strength measurements related to the stringent conditions required for target strength measurement procedures. Because the interaction between fish species and other trophic levels is going to be important to many GLOBEC questions, multiple frequency instruments are recommended. Frequencies commonly used for echo integration systems include 38, 120, 200, and 420 kHz. We recommend their use, if possible, because information about target strength for many species is available at these frequencies. Some applications which can tolerate lower accuracy in the estimation of density can benefit from the use of sonar, providing better horizontal detail of the spatial distribution of fish schools. In addition, sonars may be used to locate and track the movement of individual fish schools.

Does a change in the ocean environment affect early life history processes (e.g., larval drift, larvae distribution)?

Investigations of early life history (larvae/post larvae) require measurements of size and spatial distribution using multiple frequency systems. Ship-mounted systems can be used for studying short-term variations in distributions over larger areas. Moored systems are appropriate for studies of temporal changes in density at a few key locations over longer time periods. We recommend that multiple frequency systems be developed to assess larval and post-larval fish scatterers.

Does a change in the ocean environment result in changes in species overlap and resultant interactions (e.g., predation processes)?

When a fish predator and its prey are in the same area, the acoustic system must be able to assess a wide range of target sizes. For example, if the larval stage has a mature fish predator, the acoustic system must be capable of obtaining absolute density estimates for both groups. A multiple frequency system (either echo integration/target strength measurement system, or a multiple frequency system using an inversion technique) should provide more appropriate information. As discussed above, fish schools may be tracked through prey density fields to study local interactions (e.g., predation rates).

How is fish behavior and physiology affected by changes in environmental conditions?

Throughout the studies of fish and their relationship with their environment, information about the behavior and physiology of individual fish will be important, particularly since GLOBEC is interested in making process-oriented measurements at the level of individual organisms. Acoustic tags can be used for the study of fish depth, orientation, swimming speeds, and physiology over time. In addition, doppler sonar systems can be used to study swimming speed of both individuals and schools of fish.

How accurate are the various sampling devices (including acoustics)?

Any sampling technique may be affected by the presence of the vessel or sampling equipment. Nets are often used to obtain biological samples. Acoustic apparatus can be used to investigate the possibilities of bias when using nets. For example, sonars mounted on top of the trawl have been used to observe avoidance near the trawl. Body-mounted or vessel-mounted systems have been used to observe avoidance that occurs in front of the trawl or in reaction to the passage of the vessel. Remote, free-floating systems have been used to demonstrate avoidance of the vessel by fish, affecting both echo integration and trawl survey results.

2.2 Status of Instrumentation for Fisheries

The working group proceeded to discuss: 1) equipment that was available off the shelf; 2) equipment that was available by modifying existing equipment; 3) new technology needs; and 4) new experimental studies necessary to accomplish GLOBEC objectives relative to fisheries acoustics.

Available Instrumentation

Item	Cost	
	Instrument	Processing
Single frequency Echo Sounder (Integrator/Target Strength)	$20-100K	$60K
Multiple frequency Echo Sounder (Integrator/Target Strength)	$40-100K	$60K
Fisheries Sonar	$100-400K	not available
Net-mounted Sonar	$70K	not available
Acoustic Tags	$100-1000/tag $2000 (receiver)	not applicable

a. Modifications to Existing Equipment

The working group identified commercially available sonar systems as candidates for modification to make them suitable for measuring fish distribution. The signals in most systems are modified using an automatic gain control. Although this procedure facilitates and enhances the display capability of such systems, it removes the ability to reference to absolute echo intensity. It should be relatively easy to modify these sonars to allow measurement of absolute echo levels, for determining fish density estimates, providing the appropriate scaling data can be obtained. (Approximate cost: $25-100K, 1 year development time.)

b. New Technology Needs

The working group identified a critical need for algorithms and computer software to aid in processing, analyzing, and displaying acoustic data from multifrequency echo integration and sonar systems. Several multifrequency systems are currently in use in the community and more are under development. However, their ability to produce data is currently far greater than the community is able to digest. Methods and software have not yet been developed to quickly extract desired data from a group of pings or compare echo characteristics across frequency. Data storage schemes have not been standardized. The need for sophisticated and standardized data analysis, display, and archiving schemes is urgent. Without them we are in danger of being swamped by more data than we can comfortably digest and interpret. (Approximate cost: $1,500 K over 1 to 5 years.)

For some studies, the use of a number of single frequency, autonomous echo ranging devices, mounted on the bottom or looking horizontally from vertical moorings, may be appropriate to answer particular research needs. (Approximate cost: $200 K over one year for a ten transducer system.)

As mentioned above, doppler sonar may be appropriate to answer some behavioral questions. (Approximate cost: $200 K over one year.)

c. Experimental Study Needs

Fish target strength measurements as a function of tilt angle, depth, size, and behavior will be needed for fish species of interest to GLOBEC. This is an ongoing need for any program involved with the estimation of fish density using echo integration techniques. It is also imperative if investigators plan to attempt size estimation using target strength data. (Approximate funding required, $800 K over 3 to 5 years).

There is an urgent need to develop acoustic classification techniques (species and size identification) using echo signatures at single frequencies, multiple frequency echo intensity and target strength information, and other acoustic information from individual fish or fish schools. (Approximate cost: $500 K over 3 to 5 years.)

Since many of the processes that GLOBEC is interested in may occur near the bottom, attention should be paid to developing improved techniques for assessing fish near this boundary. (Approximate cost: $500 K over 3 to 5 years.)

Another need discussed was for studies of the relationship between fish larvae feeding and water turbulence. (Approximate cost: $200 K over one year.)

3. Macrozooplankton/Micronekton Acoustics

Chair: Tim Stanton

Participants: Steve Bollens, Dezhang Chu, Clarence Clay, Chuck Greene, Charles Greenlaw (briefly), Lee Gordon, Roger Hewitt, Van Holliday (briefly), Bob Miyamoto, Dave Potter, Doug Sameoto, Yvan Simard, Sharon Smith, Peter Wiebe, Alan Wirtz.

3.1 Introduction

Animals ranging in size from approximately 0.5 to 5.0 cm were considered in this working group. This range overlaps with the sizes discussed in the small zooplankton group, and hence, there will be overlap of the sonar frequencies used to study the two classes of animals.

Acoustical methods can support several major science objectives involving the macrozooplankton and micronekton studies within GLOBEC. In general, the acoustic techniques can help quantify the spatial and temporal distribution, abundance, and associated size distribution of the macrozooplankton and micronekton, and their predators. By varying the deployment scheme, acoustic methods can be used in studies examining biological processes in ship, Eulerian, and Lagrangian coordinate systems. Acoustic techniques can be used to examine population growth, mortality, and physical dispersion. It should be stressed that the acoustic techniques should be used simultaneously (when possible) with other methods involving: 1) nets and pumps for direct species identification; and 2) measurements of physical properties of the ocean such as salinity, conductivity, temperature, etc. for quantitative tests of coherence.

The complexity of the biological processes that need to be measured require a variety of sonar[*] configurations and deployment schemes. Much time was spent discussing these requirements with the recommendation that versatile modular sonars be developed that can be deployed in many ways. In order to improve reliability and simplicity, the sonars should have as many identical components as possible.

3.2 Overview of Sonar Techniques

A variety of techniques are available which affect the design of sonars and their deployment. The techniques can be split into two broad categories: one beam per frequency, where more emphasis is on the statistical interpretation of the echoes; and multiple beams (2 or more) per frequency, where more hardware is involved so that direct measurements of target strength are obtained when the animals are resolved as individuals. The "split-beam" sonar is placed in this latter category. The output of this phase-sensitive system provides both range and arrival angle of echoes from individually resolved animals.

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[*] In this working group report only, the term "sonar" is used generically to indicate an acoustic system. This is in agreement with the original, broad sense of the term (See Glossary). In underwater acoustics, this is often the practice, as opposed to the general usage in fisheries acoustics (hydroacoustics). In fisheries acoustics, "sonar" usually refers to horizontal echo ranging with an active acoustical system. In underwater acousfics, the term would include vertical echo sounders and passive acoustic systems, as well as horizontal detection and echo ranging systems.

All methods assume the availability of an acoustic scattering model for the transformation of echo data from voltage levels to estimates of animal size. When individual animals are not resolvable by sonar, an inversion of multifrequency, volume scattering strength data can sometimes produce an estimate of the size-frequency distribution. The assumed scattering model (or models) are implicit in the inversion algorithm. The inversion method will only work when the transition point between Rayleigh and geometric scattering is within the range of frequencies used in the acoustic system. For frequencies typically used in the assessment of macrozooplankton (10's to 100's of kHz), the inversion method would only apply to populations involving macrozooplankton of a few centimeters in size or smaller.

When the individual animals are resolved, deconvolution, dual-beam, and split-beam methods can be used to produce distributions of echo amplitude or target strength. With the use of an appropriate scattering model, that data can then be used to estimate size-frequency distributions. When individual animals are not resolved, systems involving the deconvolution, dual-beam, or split-beam methods can produce echo integration data, scaled by target strengths of individuals (perhaps measured at a nearby location where the animals are similar), to estimate biomass.

The advantages of the different methods were discussed. Clearly, when individual animals can not be resolved, echo integration techniques need to be used. One beam per frequency is sufficient in that case. If the individual animals can be resolved, tradeoffs arise between the use of one beam and multiple beam per frequency systems. One beam per frequency systems require less hardware per frequency, but more effort in the development of processing algorithms. Whereas, multiple beam per frequency systems require more hardware per frequency, but less effort in the development of algorithms. We concluded that comparative studies between the approaches should be conducted as soon as possible.

a. One Beam per Frequency

Two inversion techniques have been developed for extracting animal size information from acoustic backscattering data. One uses a multifrequency sonar, the MAPS (Multifrequency Acoustic Profiling System; Holliday et al., 1989; Pieper and Holliday, 1984), while the other, which involves a deconvolution, can be used on single frequency or multiple frequency systems (Clay, 1983; Stanton and Clay, 1986). Both methods involve "accepting" scattering data from the animals in all parts of the acoustic beam. The MAPS is particularly successful when individual animals are not resolved. It can, however, work equally well in a uniform distribution of resolved targets, if given enough time at each point in space. Beam effects are taken into account once the data are averaged. The deconvolution approach requires that the individual animals be resolved. Beam effects are removed from the data using this technique and the result is a set of echo amplitude histograms. Both techniques rely on applying mathematical inversion methods in the post-processing software. While the software that contains the algorithms currently resides in the laboratories of Holliday, Pieper, and Clay, the math is well known (Lawson and Hansen, 1974; Holliday, 1977; Leih and Holliday, 1982; Clay, 1983) and is standard in other disciplines such as seismology.

The MAPS technique has been used in a number of field studies involving zooplankton while the deconvolution technique has been applied almost exclusively to echoes from larger sized targets such as fish. The latter method has been used at least once to extract zooplankton size distributions from echo data (Stanton and Clay, unpublished). The agreement between size distributions estimated acoustically and from net/pump collected samples has been very encouraging with both acoustic methods.

b. Multiple Beams per Frequency—Target Strength Estimation Techniques

Two techniques have been developed to directly estimate the target strengths of fish: the dual-beam technique (e.g., Ehrenberg, 1974; Traynor and Ehrenberg, 1979); and the split-beam technique (Ehrenberg, 1979; Traynor and Ehrenberg, in press). The methods involve comparing the outputs of each of the two (dual-beam) or four (split-beam) beam channels so that the target strengths can be determined directly. While both methods were originally developed for detection and quantification of fish schools, the dual-beam technique has recently been used in studies of zooplankton and micronekton (Richter, 1985a,b; Greene et al., 1989; Wiebe et al., 1990), and a split-beam system has been used to study deep-sea micronekton (Smith et al., 1989). Recent technological advances in the dual-beam technique have made it feasible to analyze in situ the single echoes returning from individual zooplankters as small as several millimeters. Finally, it is important to stress that, although the dual- and split-beam systems produce a single value of target strength for each echo, the target strength is highly variable with each animal. This variability mandates the collection of a statistical ensemble of echoes for the animals to be studied. For a given sampling volume, the same number of pings are required for all methods, single or multiple beam.

3.3 Overview of Acoustic Sampling Methods

The design of acoustic measurements is tied intimately to the length of the organism relative to the acoustic wavelength and the density (number/unit volume) relative to the resolution of the sonar. The specific instrumentation packages and deployments change for the different sizes and densities (number/unit volume) of objects and biological processes being studied. Because of the wide variety of organism sizes (including predator and prey) and their spatial and temporal variability, there is no standard mode of deployment or commercially available sonar system that can meet all GLOBEC science objectives concerning macrozooplankton and micronekton. We therefore recommend the following sonars with a variety of deployment modes.

a. Modes of Deployment

The following three deployment modes are recommended as particularly useful in GLOBEC studies.

Ship-mounted or towed survey systems

This system would provide survey data during transects taken in conjunction with physical measurements of the ocean (CTD, etc.). These data could loosely be called "synoptic". We concluded, however, that given the finite amount of time it takes to conduct a transect, the features may change enough so that the data are not a true acoustic snapshot of the region, hence the terminology "survey".

Ship-based cast or tow-yo systems

These systems, deployed from the ship, would provide a data set to complement the survey by providing a closer look at the organisms via the cast or tow-yo methods. Higher spatial resolution is obtainable in this mode. Furthermore, by use of a side scan configuration at the deeper depths, one can measure horizontal spatial distribution.

Remotely deployed systems

These systems would involve a sonar(s) mounted on freely drifting buoys, freely drifting neutrally buoyant platforms, remotely operated vehicles (ROV's), bottom mounted/moored platforms, or yo-yo platforms (standalone systems that periodically move up and down in the water column). The drifting systems address the requirement for performing times series analysis in Lagrangian coordinates while the latter two conduct times series measurements in Eulerian coordinates.

The details of the above modes of deployment will be discussed in later sections in the context of the acoustic measurements.

3.4 Recommendations for Sonar Design

We envision a number of sonars for eventual use in the GLOBEC program. In order to improve on the reliability and flexibility of the systems, we recommend that most components of the above sonars be modular and identical. Naturally, the remotely deployed systems require changes in power and sampling strategies. The sampling or ping rate, for example, could be a programmable feature.

The various functions of the sonars such as logic or transceiver electronics should be constructed on separate electronic "cards" that plug into a card cage or rack. The size of the cage and number of cards would depend upon the number of frequencies used. The sampling strategy or sequence of pings that is specific to the particular sonar configuration, deployment, and biological process can be programmed into the logic card that all systems would have in common. For example, a shipboard survey system may be acquiring data on all sonar channels continuously and simultaneously, hence requiring a continuous supply of power. Because of power constraints, the remotely deployed Systems would need to turn off automatically between pinging sequences. As a result, the system would be turned off most of the time to minimize depletion of battery power. There would be a difference in power supply sections of the cages depending upon whether the system would receive AC shipboard power or DC battery power in a remotely deployed system.

We listed all commercially available sonars and came to the conclusion that no such system as described above exists. Furthermore, there is no system available that could be easily modified to fulfill the needs of the GLOBEC program. The system that comes closest to meeting the needs of this program is one currently under development by Clay at the University of Wisconsin (NSF funding). It is modular and can provide acoustic signals at a variety of frequencies, although it requires AC power. As a minimum, the system would need to be modified so that it could: 1) accept DC power at low consumption rates (e.g., by use of low power integrated circuit components); and 2) have adaptive sampling modes to allow for variable sampling schemes that depend upon the available power. With all of these factors included, we recommend that a sonar system be developed, with attention initially being paid to the design of prototype systems, such as that under development at the University of Wisconsin.

Since deployment of sonars are specific to each biological process under investigation, we recommend that the "platform" for each type of deployment be addressed on a case-by-case basis by the user (science P.1.) and be built by, or subcontracted to be built for, the user.

a. Acoustic Frequencies

It is clear from the scattering behavior of animals, that in order to discriminate various sizes of the animals, one must use a broad range of frequencies. Practical limits on the size of transducers provide the lower limit of frequency, while absorption of sound determines the upper limit of frequency. We recommend frequencies between 38-420 kHz be used. These end points correspond to the frequencies of systems that are available commercially. Although the system described here should be built from the ground up, we recommend that some of the frequencies be identical to those of off-the-shelf units to allow comparisons between historical data and data collected with the new system. The number of frequencies required depends upon interpretation methods used and power requirements (when the units are remotely deployed). We recommend that a minimum of 3 frequencies be used and a maximum of approximately 8-10.

b. Sonar Resolution

Since animals may sometimes occur at densities much greater than one per cubic meter, it is not practical for all sonars to be able to resolve individual animals in all situations. Some systems under certain deployment schemes, however, should be able to resolve individuals so that direct estimates of density and statistical properties of patchiness can be made.

c. Survey System

Acoustical surveys from surface-deployed systems can rapidly map in three-dimensions the distributions of biological sound scatterers within large volumes of water Surveys such as these can be used to assess patchiness on the scales of 10's to 100's of meters, the spatio-temporal coupling of predator and prey populations, and the effects of physical and topographic features on animal distributions.

This system, as well as the use of other remote sonar systems, could provide water column acoustic data (echograms) during transects and help direct the location and timing of "point" sample methods (nets, etc.) The echogram would also help place the various point measurements into the context of the complex ocean structure during later analysis. The system would include the maximum number of acoustic frequencies, store massive amounts of raw data at high speed, and provide high quality acoustic data for sophisticated interpretation.

We recommend that the system be operated at fixed depth with the option of being lowered to depths near scattering layers to examine the layers at higher resolution. All sonars on the tow body should transmit their signals simultaneously (as opposed to sequentially) and the echoes should be acquired simultaneously so that the various echoes can be associated with the same sampling volume. The beamwidths should be similar or identical to help achieve this goal. The approach of using simultaneous transmissions and acquisition also minimizes the time between acoustic transmissions for each frequency and allows for maximum resolution of the patch structures.

d. ROV, Profiling, and Towed Systems

While the survey system can provide a picture of the distributions of the sound scatterers over a large volume of the ocean, much of the data collected represents organisms located at great distance from the sonar. The spatial resolution of each sonar decreases with increasing distance from the sonar, and as a result there is a loss of the lower end of spatial scale that can be measured at those ranges. The survey system can occasionally be lowered to increase the resolution, but this may result in the loss of survey data. We recommend that other sonars be deployed in or near a region of scatterers in order to improve the spatial resolution of the measurements.

There are a variety of platforms that can be used to deploy sonars from a ship -- submersibles, remotely operated vehicles, vertically profiling instruments (e.g., MAPS), towed vehicles (e.g., Batfish, MAPS, V-fin, etc.), nets (e.g., MOCNESS or BIONESS), and trawls. The first few platforms can be used to acoustically explore concentrations of interest while deploying a sonar on a net or trawl, thereby providing some degree of ground truth and species identification information in concert with the acoustical data set.

e. Free-Drifting Buoy and Bottom Mounted/Moored Systems

Measurements need to be performed in coordinate systems besides that of a ship. It is important to study distributions of animals at fixed locations (Eulerian) and on platforms that are allowed to drift with the flow of the water (Lagrangian).

The changes in acoustic scattering levels at the proposed GLOBEC study sites will vary on time scales ranging from daily to seasonal to yearly. While in some of these areas the general levels of volume reverberation are predictable to some extent, the biological and physical factors which affect the levels are not well understood. As a result, the reverberation levels are not sufficiently predictable. Most studies of acoustic backscattering in the oceans have been conducted from ships which limit the duration, areal coverage, and vertical extent of the data. Autonomous free-drifting buoys and bottom mounted moorings can solve this problem. They should be equipped with echo sounder electronics and transducers, a digital signal processor, data storage, and satellite and radio communications systems. These systems can be used to periodically and frequently collect high frequency backscattering information (for example, 120 kHz and 420 kHz) from remote locations and relay the information to a ship or shore location in real-time. Because the systems are autonomous, with finite electrical energy and computer memory, the sampling strategies must be carefully adapted to the biological process of interest to make the most of those quantities.

Envisioned in both the surface free-drifting system and the moored instrument is an acoustic system which includes two or three frequencies which can be sequentially activated. Profiles of acoustic backscattering would be obtained at depth intervals (nominally 1 m) to a maximum range of operation which is frequency dependent (typically 10's of meters to ca 200 m). In order to adapt the sampling protocols to the phenomena being studied, the instrument package needs to be programmable so that a duty cycle of choice can be selected and echo sounder parameters such as pulse length and processing criteria can be altered. Data to be collected could include individual target strengths as a function of range and average backscattering strength for each depth interval. Data would be stored on a mass storage unit (e.g., an optical disk) in the buoy or mooring unit for post processing. Reduced data in the form of a target strength histogram, and integrated intensity for a reduced set of depth intervals at each frequency averaged over some time interval (i.e., 2 hrs), would be produced for daily transmission via satellite to shore. Real-time, two-way radio telemetry should also be available.

Bottom mounted acoustic systems can be used to measure the acoustic scattering by animals located at and near the bottom. Depending on the application, the systems could be used to look vertically (up or down), horizontally, or at other angles. Because of the difficulty of bottom interference with measurements in the horizontal or downward directions, new acoustic techniques must be applied. These new techniques should utilize vertical split beams to resolve bottom versus near bottom animals and make comparisons between pings to determine slight changes in the acoustic scattering due to bottom animals. This ability to measure macrozooplankton on, or very close to, the bottom will be an exceedingly important capability in areas such as Georges Bank where very large demersal shoals occur during the daytime. For maximum coverage of the surrounding volume of water, one may consider mounting the sonar on a rotating vertical shaft so that the region may be scanned much like a radar system (electronic steering via beamforming is also a possibility, although the complexity of the electronics is increased).

3.5 Team Responsible for Acoustic Systems

The maintenance, calibration, refinement, and further development (especially of software) of the above acoustic systems is beyond the experience of most biologists and end users of such systems. Therefore, it is essential that a team of experts (2 or 3) in acoustics, electronics, and software be assigned responsibility of ensuring that the system is calibrated and operating to the proper specifications before and after each cruise. This type of facility-level support is certainly available in other disciplines, such as geoacoustics, where the operation and maintenance of the Sea Beam multibeam bathymetry system is provided.

Specific tasks of the team would include: 1) ensuring that the mechanical terminations of the cable and the various wire connections are maintained during the cruises; 2) developing the basic software for recording and storing the data which would be modified to suit the various users; 3) matching the acoustic system to the different ships before each cruise; 4) responsibility for trouble shooting problems during the cruise; 5) maintenance and operation of the winch and care of the tow cable and the towed body; 6) ensuring that acquired data is of the highest quality, and that the researcher is notified of any malfunction during the survey. This means that the team must be responsible for data acquisition at all times; and 7) documenting the protocol for calibration and maintenance so that changes in personnel will not affect calibration and maintenance procedures.

The above mentioned responsibilities, which do not represent all of the anticipated tasks, are a consuming job and justify a dedicated team.

3.6 Format of Data/Data Management

Data must be archived and easily exchanged between programs to meet GLOBEC objectives. To facilitate this exchange we recommend the following actions. Data should be digitized and in scientific units (e.g., m^2, dB//µPa, etc.). The type of data should be explicitly described (e.g., raw acoustic, biomass, target strength). All relevant information should be fused to the data and should include synchronization of date, time, position, instrument values (e.g., sample rates, noise levels, bandwidths), calibration information, processing information (ping averages, bin depths), and any other ancillary information (temperature, salinity, etc.). Finally, a data interchange format should be developed that will permit archiving and exchange of acoustic data. An interchange format is desirable since many commercial instruments will have proprietary data formats and it is unlikely that one format can be defined for all data acquisition systems.

Data should be archived and merged with non-acoustic information at a central data management facility. This facility is essential to maintaining information for the climatic time scale experiments.

3.7 Other Systems

While we recommend the use of the modular sonar approach described above, which can perform a suite of measurements under a wide variety of conditions, there are other systems that should be considered. These systems can provide types of data not otherwise obtainable.

a. 3-D Imaging Sonar

This planar sonar array can be used to produce three-dimensional images of the volume of interest. The "images" indicate the location of animals and their echo levels so that the spatial density and inter-animal separations can be directly measured. No indirect interpretation technique is required to provide such information. By tracking the animal through the acoustic beam and recording the statistics of its time-varying echo levels, classification would be possible by use of scattering models. This type of system is currently under development both at SIO (Jaffe) and WHOI (Stanton).

b. Acoustic Doppler Current Profiler

The Acoustic Doppler Current Profiler (ADCP) estimates water motion by measuring the frequency of reverberation from different depths in the water column. In comparison to most acoustic instruments used to study oceanic organisms, this instrument transmits very long pulses so that the doppler shift induced by motions of the animals can be detected and resolved. An implementation of this technology is commercially available from RDI. This system is used routinely to obtain estimates of water current profiles under the assumption that the composite motion of the animals which dominate the sound scattering reflect the motions of the water mass.

The motions measured include both active swimming and passive advection. Researchers could potentially use doppler information to study animal behavior, e.g., vertical migration. A quantity related to volume backscattering strength can also be measured with currently available ADCP's. With absolute system acoustic calibration and careful attention to a variety of stability issues (Flagg and Smith, 1989a, 1989b), such information is potentially useful to biological oceanographers.

c. Passive Localization

While all of the above-mentioned techniques involve active acoustic methods in which a burst of sound is transmitted into the water and the resultant echoes are detected for localization and classification purposes, one can also take advantage of the fact that some animals (fish included) generate their own sound. In particular, some species of fish generate sound during the time of spawning. A grid of hydrophones could be used to pick up sounds from individuals or schools. Triangulation or even tomographic methods could then be used to estimate the location of the animals. Classification of animals by the nature of the sounds they make could be possible if the properties of the sounds that are generated by various species were known.

3.8 Summary of Recommendations

We must address the complex needs of the GLOBEC science objectives with a versatile set of sonars and deployment schemes. This requires:

1) The development of a sonar whose components are modular and interchangeable so that the same design can be used to meet all needs of the program. Ultimately a number of duplicate system components would be constructed so that a variety of acoustic systems could be assembled;

2) The establishment of a facility(ies) where a permanent team of specialists maintains, operates, and refines the acoustic hardware and software. Such a facility would be similar to what is available in other disciplines and would allow the user to concentrate on achieving the science objectives;

3) Use of other acoustic systems such as a 3-D imager, doppler profiler, or passive localizer to provide other forms of data; and

4) The establishment of data archive protocols to facilitate long term (10's of years) use of the data.

The development and construction of sonars with the attributes discussed above was considered to be appropriate for inclusion within future "Calls for Proposals" from the GLOBEC program.

Finally, it was agreed that any hardware associated with the deployment of the sonars such as tow-body, drifting buoy, etc. should be treated on a case-by-case basis by the users in their respective science proposals.

4. Small Zooplankton Acoustics Working Group

Chair: Rick Pieper
Rapporteur: Mark Ohman

Participants: Marvin Blizard, Jack Green, Charles Flagg, Van Holliday (briefly), Mark Huntley (briefly)

4.1 Introduction

The organisms addressed by this group were initially defined as those for which the fluid sphere acoustic scattering model is appropriate. We later extended this definition to encompass somewhat larger, euphausiid-sized organisms.

A high priority was placed on developing multiple-frequency instruments that simultaneously sense several size classes of zooplankton. This resolution of body size is important given that zooplankton growth rates and predator-prey interactions are known to vary with body size. The ability to interpret acoustic backscattering profiles, to understand behavioral differences among species, and to distinguish changes in marine ecosystem structure also require resolution of acoustic backscattering into several size classes. Acoustic validation of population and ecosystem models will also require size class resolution.

4.2 Modes of Deployment

The mode of deployment for zooplankton acoustics instruments may vary with the GLOBEC study site. We discussed the advantages and limitations of both Eulerian and Lagrangian techniques and agreed that a system must be sufficiently flexible to be deployed in several ways: 1) from surface ships on vertically profiling instruments, or on nets; 2) on moorings; or 3) on drifters.

4.3 Priorities for Instrumentation Development

The following subjects pertaining to the development and acquisition of instrumentation and related basic research are considered appropriate for inclusion in future "Calls for Proposals" in support of GLOBEC science objectives.

a. Priority 1

The highest priority was placed on the development of a single, standardized acoustic system to resolve multiple classes of zooplankton. Such a system must be sufficiently versatile to serve a variety of purposes and sufficiently inexpensive to allow deployment of several within one study region. The Working Group agreed that resolving *ca* 5 size classes of zooplankton in the size range of 1-20 mm in length would be useful for many purposes, while retaining the essential attributes of instrument portability and low cost. The processed output from the instrument should be either number of organisms per m^3 or biomass of organisms per m^3 in each size class. The chief characteristics of such a system would include the following:

- Capability to resolve *ca* 5 size classes of zooplankton;
- Relatively simple to deploy and operate;
- Relatively inexpensive;
- Low power requirements;
- Internal signal pre-processing (in replaceable EPROM's to retain algorithm flexibility); and
- Option for either real-time transmission of data or internal storage.

The approximate size classes and a few representative crustacean organisms are provided in the table below.

Representative Organisms and Size Classes of Interest

Length (mm)	ESD (mm)	ESR (mm)	Representative Organisms
1.2	0.5	0.25	Small copepods *Pseudocalanus, Acartia Paracalanus, Calanus* copepodites
2.5	1.0	0.5	Adult *Calanus, Metridia*
5.0	2.0	1.0	Adult *Eucalanus, Neocalanus, Euchaeta,* larval euphausiids
10.0	4.0	2.0	Juvenile euphausiids, mysids, amphipods
20.0	8.0	4.0	Adult euphausiids, mysids, amphipods

The probable end points for transducer frequencies are *ca* 3 MHz for the smallest size class and *ca* 100 kHz for the largest size class. Final selection of the target size classes and acoustic frequencies should be done by examination of existing zooplankton size frequency distributions from different ocean basins, and in consultation with acousticians (e.g., computer modeling). The instrument should be built in modular fashion so that different transducers may be substituted; the number of frequencies may be greater than the number of desired size classes, depending on the method(s) employed and cost considerations.

Fundamental to the design of the instrument is a low profile, versatile underwater package. The package must be capable of being deployed in the following ways:

- Lagrangian drifters (at a fixed depth or in Cyclosonde mode);
- Moorings;
- CTD systems;

- Surface vessels; and

- MOCNESS/BIONESS towed net systems.

The instrument should have an internal built-in-test capability to verify the stability of the electronics and should also be calibrated periodically (e.g., annually) at a transducer calibration facility.

Flexible post-collection data processing software should be developed in conjunction with the acoustic device. This software should permit data to be aggregated in variable bin sizes; means and standard errors computed by depth, time, or scan; contouring; and plotting of vertical profiles, sections, and time series plots. The software should have "open architecture" to allow other variables (e.g., fluorescence, CTD, or thermistor data) to be processed in a similar manner and should accommodate user customization (e.g., flexible database structure).

Procurement Considerations and Timing

The development and construction of an acoustic instrument with attributes similar to those discussed above were considered to be appropriate for inclusion within future "Calls for Proposals" from the GLOBEC program. In order to have a maximal impact on GLOBEC science, development of this instrument should strive for prototype completion within 18 months, including comparisons with pump and net zooplankton samples. Potential manufacturers for the production instrument should be identified as early as possible. The manufacturer(s) should be encouraged to vigorously pursue construction and marketing. The advantage of such an instrument to a manufacturer is the establishment of a "standard" instrument with a worldwide market. Two of the operational advantages of this instrument to the scientific community are the broad base of user knowledge and the ability to compare results between study sites.

Other considerations

We recognize that gelatinous zooplankton (e.g., salps, larvaceans, medusae, ctenophores) can dominate marine zooplankton assemblages. In some cases, they do so as transients in rapid population bursts. Better methods are needed to acoustically distinguish gelatinous organisms from non gelatinous. Experimental study of target strengths and unique acoustic signatures of these organisms are needed.

We recognize the need to sample eggs, nauplii, and juvenile stages of many species of zooplankton. We recommend that acoustic methods be compared to other methods for achieving this. If sensor costs imposed by the need to offset the extreme acoustical attenuation at high frequencies substantially increase the overall system cost, then sampling these smaller organisms might best be done with optical measurements (e.g., High Definition TV) in combination with the acoustic instrument described here.

We underscore the need for collection of pump and net samples to collect "ground truth" data, (e.g., species identification) for the acoustic instrument. This will necessitate accelerated development of rapid, automated means to enumerate and identify zooplankton samples.

b. Priority 2

Swimming speed of zooplankton is a critical parameter for prey-predator encounter models. Swimming speed is also useful for understanding vertical migration behavior and may help identify the organisms in specific acoustic size classes. We recommend using doppler shift/spread from swimming zooplankton to estimate swimming speeds of organisms *in situ.* High frequencies *(ca* 3 MHz) will likely be most useful for this purpose.

The doppler shift due to swimming zooplankton can be obtained by Fast Fourier Transform methods (among others). Changes in the average doppler shift and the doppler spectrum width of volume reverberation from a volume of water may indicate the mean and extreme swimming speeds of a group of zooplankters. Relatively straightforward modifications to the Priority 1 instrument should permit the doppler parameters to be measured, combining measurements of zooplankton abundance with measurements of zooplankton swimming speeds.

c. Priority 3

A low-cost Expendable Acoustic Profiler (EAP) could be a useful tool to aid in conducting rapid surveys. Deployment of EAP's from ships-of-opportunity, or possibly aircraft, would increase spatial and/or temporal coverage of more isolated study sites. EAP's could also enable a large-scale region to be mapped prior to conducting more detailed sampling. Although there was not unanimous agreement on the utility of this instrument, some working group members supported development of an EAP capability. EAP's might be manufactured with a variety of single frequency transducers.

4.4 Development of Backscattering Models and Bioacoustical Instruments

The working group concentrated its efforts on the specifications and need to develop a simplified, standardized acoustic system for use by the general community of researchers. We also recognize and support the need to refine and improve acoustic backscattering models and instrument design. In conjunction with the simplified system described above, we support the continued development of more sophisticated multi-frequency acoustic systems, along with acoustic scattering model development, for advanced research and development.

5. Acoustical and Optical Sensor Integration

Chairman: Peter Ortner
Rapporteur: Lewis Incze

Participants: Charles Barans, Mark Berman, Cabell Davis, Brad Doyle, Charles Greenlaw, Alex Herman, Van Holliday (briefly), Mark Huntley (briefly), Jules Jaffe, Gus Paffenhöfer and Rudi Strickler

5.1 Scientific Context

GLOBEC intends to study the population dynamics of key species and the processes controlling their abundance in a variety of marine ecosystems. The first field program will study Georges Bank and will focus, at least initially, on the copepod *Calanus finmarchicus* and on the early life history of cod, *Gadus morhua.* Virtually all biological rates are assumed to be modulated by physical conditions and motions. The influence of physics on biology occurs over a wide range of spatial and temporal scales. The population-level response of *Calanus* on Georges Bank depends upon, among other factors, the spatial extent, seasonal timing, frequency and amplitude of external forcing from atmospheric weather, oceanic anomalies (e.g., Gulf Stream rings), cross-bank advection, and the migrations of predator populations (e.g., fish). The goal of GLOBEC is to understand, and ultimately to predict, population changes by determining (from first principles) the processes affecting variability in population abundance. That is, GLOBEC seeks to understand the combination of physical and biological interactions affecting reproduction, distribution, and mortality of selected taxa. This requires identification and documentation of small-scale processes and distributions and then quantitative linkage between these processes and larger-scale forcing functions.

5.2 Working Group Deliberations

Members of the working group agreed that the following observation problems would have to be resolved to meet GLOBEC's stated goals.

a. Distribution

- We must be able to describe a population's distribution pattern quasi-synoptically at low resolution and with high spatial and temporal resolution at critical points within this coarse field pattern. Therefore, we must be able to rapidly assess and identify selected target species.

- We must be able to follow a study unit of the population through time, studying its structure in three dimensions as its dynamics affect organism-organism interactions.

b. Scale Linkage

We must discover and document whatever linkages exist among the various temporal and spatial scales in order to relate small-scale processes (those affecting the individual) to population level responses. We must understand how these various time and space scales are mechanistically connected and must design appropriate observational techniques to obtain the necessary data to validate models of population response to climatic conditions.

c. Processes

We must be able to measure relevant biological processes and understand their variability among individuals under different conditions at spatial and temporal scales relevant to the particular process. Such processes include grazing, predator/prey interactions, and mating and reproduction. We felt our principal task was to consider whether, and to what degree, an integration of biooptical and bioacoustic sensor technology could address these problems and how they might be addressed realistically given the state-of-the-art and the prospects for advances in sampling technology.

As an initial exercise we attempted to specify, *a priori*, what reciprocal benefits could be obtained by merging technologies or obtaining complementary data. From the viewpoint of bio-optical system users, bioacoustics could fill the following needs:

1) Provide a spatial map of the broad scale distribution of selected taxa and pinpoint features of interest for fine-scale process studies;

2) Provide data on vertical migrations;

3) Provide data on larger-scale three dimensional structure;

4) Make it possible to track a group of organisms over periods enabling a series of process studies to be made;

5) Provide doppler measurements of swimming speeds and statistics on population behavior (e.g., number swimming up/down/not at all); and

6) Provide information on larger, rarer organisms that might constitute predators upon organisms whose interactions are being studied with current bio-optical systems.

From the viewpoint of bio-acousticians, bio-optics could fill the following needs:

1) Provide information on target orientation;

2) Provide independent size distribution estimates perhaps as transect sample series data (e.g., utilizing current towed platforms like UOR, SeaSoar, or Batfish) within a bioacoustic map; and

3) Provide taxonomic identification of bioacoustic targets.

All participants agreed simultaneous sampling with traditional sampling devices (nets, pumps) was still essential since no single method was sufficient, and confidence in accuracy could only be obtained by using independent methods and ascertaining the degree to which their estimates converged. All participants agreed that GLOBEC's objectives implied concomitant physical (temperature, salinity, and current) data collection. Quite likely physical, bio-optical, and bioacoustical methods would have to be integrated to obtain estimates of micro- and fine-scale turbulence and its effects on behavior and organism-organism interactions.

Current bio-optical methods sample in close proximity to the sensor. Bioacoustic methods sample on nearly the same scale but can also sample larger water volumes much further away from the sensor. At these large scales bioacoustic methods sacrifice resolution. This loss, however, may not be the greatest problem to be faced in linking various scales. The group felt the more difficult problem will be confidently linking 1 mm to 1 cm individual organism behavioral scales to 100 m to km subpopulation scales. Last, although we felt the scale problem was likely to be a primary issue in the Fisheries Acoustic Working Group, the participants recognized that while GLOBEC is focusing on key species in the plankton the bioacoustic survey systems used will have to encompass the lower frequencies necessary to sample larger organisms such as euphausiids and fish.

d. Available Technology

Prior to detailing specific recommendations the group enumerated promising bio-optical or bioacoustic technologies and instruments and tried to characterize their relative costs and availability. We described the following general groups.

Some instruments holding promise for GLOBEC are currently available off-the-shelf for comparatively moderate cost. These include the following devices:

1) Optical Plankton Counter (laboratory or towed) - A towed or profiling sensor used to count and size zooplankton in the 0.25 mm - 3.0 cm range. It was developed by A. Herman of the Bedford Institute and is commercially available from Focal Technology, Inc.;

2) CritterCam [R] (laboratory, lowered on a cable, mounted on a submersible or a ROV) - This camera system using an IR diode laser was developed by J.R. Strickler. It is commercially available from LNG Technical Services;

3) ADCP Backscatter (vessel mounted or moored) - Software and hardware are now commercially available for this purpose from RDI, Inc. The method was described in the literature by C. Flagg and S. Smith;

4) Commercial Echo Integration (dual- or split-beam on towed bodies or vessel mounted) - Dual-beam systems at various frequencies currently are available from various manufacturers including BioSonics, Inc. Results using these systems to sample micronekton have been published by C. Greene and P. Wiebe. Split-beam systems are available from Simrad.

Other instrument systems require modification or adaptation to be applicable to GLOBEC problems. Others have only been developed as prototypes in certain laboratories. As a result these will likely cost more money to bring on-line. These include the following instruments:

1) Moored: OPC, CritterCam [R] (video systems or serial plankton recorders) - The OPC system that might be used in this application is under development and is substantially different from that commercially available today. A plankton recorder of this type has been developed and used at WHOI (C. Butman). Field trials with a moored CritterCam[R] are planned for the fall of 1991;

2) Video Plankton Recorder (VPR) - A towed video camera system under development at

WHOI. It is intended to sample on centimeter scales over many kilometer transects;

3) Plankton Image Analyzer- A device developed at URI/NMFS-Narragansett to enumerate samples of zooplankton or their recorded images and classify individuals into taxonomic groups;

4) Simple Multiple-frequency Systems- Systems of this type are under development at a number of institutions. A prototype of a fully modular quantitative echo-integration system employing up to six frequencies, and capable of real-time data analysis and display, has been deployed on MOCNESS and *in situ* plankton cameras by NOAA/AOML and Tracor investigators. Development is also underway on such systems in Norway (Dalen), at BIO in Canada (Sameoto), and at the University of Wisconsin (Clay);

5) Commercial ROVS with Bioacoustic Imaging/Location Systems - (Greene *et al.,* 1991).

6) High Resolution "Shadowgraph" Side-scan Sonar- A system of this type was used by C. Barans and V. Holliday to sample large demersal fish species.

The final category includes systems or methods that are likely to be costly either initially because of large research and development commitments (although the individual units eventually may be produced at moderate cost), or because they are inherently complex and likely to remain expensive. For the latter group a "facility" model of operation and maintenance may be required.

1) Major Research and Development Projects

   - Improve video image analysis from broad taxa to species level identification; and
   - Provide visual verification of bioacoustic sampling of large fish to attain species-level identification.

2) Potential Facilities

   - Laser range-gated imaging-- Such a system is under development at MBARI and is theoretically capable of resolving millimeter scales at distances of many meters;
   - Holographic imaging;
   - Confocal imaging;
   - 3-D bioacoustic imaging- Such a system is under development at SIO/MPL and WHOI, and will resolve three dimensional structure in zooplankton communities at distances of tens of meters; and
   - Multifrequency Acoustic Profiling System (MAPS)- This system was developed several years ago by Holliday and Pieper. It employs 21 individual transducers ranging from 100 kHz to 10 MHz to generate size frequency distributions in 21 independent size classes.

5.3 Specific Recommendations

Integrate bioacoustic and bio-optical sampling technology so as to reduce the ambiguity inherent to purely bioacoustical measurements.

Without target identification bioacoustic measurements of the biota will not provide the information required by GLOBEC. Optical data can efficiently provide much of the requisite calibration data (including e.g., target orientation information). In addition to these bio-optical data traditional sampling will be required to ground-truth indirect methodologies. Such integration currently is being pursued and needs to be more explicitly emphasized as especially fundamental to GLOBEC.

Utilize bioacoustic sampling to extrapolate bio-optically based process information to larger time and space scales.

Video and camera information on organism behavior and feeding are typically obtained on small sample volumes over comparatively short time scales. By nesting such experiments inside larger-scale bioacoustic maps the results can be generalized to the regional or population level.

Develop bioacoustic and bio-optical techniques that provide information within a 1 m^3 volume to characterize processes operating on scales <1 cm.

At the present time no such systems are readily available but are considered to be essential to GLOBEC's fundamental process orientation given the size of the target organisms selected. Both technologies can resolve targets on these scales and would be employed most fruitfully in conjunction with one another.

Develop processing and analysis technology to the point where population distributions of target organisms can be visualized in near real-time.

Without such advances it will be impossible to accomplish certain GLOBEC requirements including sampling a coherent population over time and conducting a series of process or behavioral experiments at the scales implicit in the GLOBEC program.

Develop integrated bio-optical and bioacoustic systems that can be deployed at various depths on fixed moorings instrumented with physical (temperature, salinity, and current) and chemical (fluorescence) sensors.

Such systems are likely to be required by GLOBEC in its initial field program to characterize the advection of biological populations on and off shallow banks. They should be designed with the capability of 2-way telemetry so that sampling rates can be modified if unusual events are detected, and to monitor system performance. They also could be equipped with sample collection systems of various kinds.

Explicitly recognize the significant problems of data assimilation, archiving, and retrieval inherent in utilization of such bioacoustic and bio-optical sampling systems.

These systems generate volumes of data orders of magnitude larger than we are currently equipped to process and store. Simple storage of raw data is likely precluded. Whatever systems are eventually adopted will doubtless be dependent upon the availability of sufficient computer capability at sea to analyze raw data and transform it into manageable processed units like images or maps. An advanced computer system needs to be placed on at least one ship to be used in GLOBEC. Moreover, the accumulation of data may well exceed even enhanced shipboard storage capacities and a high-speed data link to shore via satellite communication will be essential. The same facility may be critical to coordinate the activities of multiple platforms during a GLOBEC field experiment.

Develop bio-optically and bioacoustically instrumented Lagrangian platforms that can be deployed at various depths (or are capable of changing depth) so as to follow a targeted population.

This application presents special technical challenges beyond deploying similar systems on fixed moorings. It may not be essential to GLOBEC in its early phase but may become essential when the behavioral responses of target populations and the most significant regulatory processes are better understood.

Modify commercial echo sounder technology to the higher frequencies suitable for initial GLOBEC target organisms (copepods) to permit routine (although perhaps not entirely quantitative) mapping.

This approach is felt to present few technical challenges and to be especially cost-efficient.

6. Discussion on Education and Training

Chairman: Chuck Greene
Panel Members: Steve Brandt, Rudi Strickler

6.1 Human Resources Development in Bioacoustical Oceanography

Bioacoustical oceanographic technology will contribute to the achievement of GLOBEC objectives in direct proportion to the size and quality of its user group. At present, the user group is small and training is done on a relatively informal basis. In the next few years, it is imperative that we begin to develop a more formal training program which will be available to the whole ocean sciences community and will provide rigorous, high-quality training to the next generation of bioacoustical oceanographers. The alternative is a situation in which the technological needs of GLOBEC overwhelm the ocean science community's ability to respond.

The foundation for a formal training program in bioacoustical oceanography could be a basic graduate-level course modeled after the bio-optical oceanography course taught at Friday Harbor Laboratories. This course has provided rigorous training in bio-optical oceanography for dozens of graduate students over the last seven or eight years. In turn, these students have gone on to become the critical mass for bio-optical oceanography's rapid advancement and acceptance within the biological oceanographic community. The potential for a similar course in bioacoustical oceanography is great; a possible course outline might include the following topics.

- Principles of Underwater Sound -- Week 1

- Bioacoustical Oceanographic Methods -- Weeks 2 and 3
    - multi-frequency inversion methods
    - multi- and split-beam methods
    - doppler methods

- Group Field Study -- Week 4

The bioacoustical oceanography basic course should emphasize: 1) a practical, "hands on" approach to learning; 2) an equal emphasis on acoustical methods and biological oceanographic applications; and 3) exposure to the expertise and instruction of visiting lecturers from a variety of institutions. This multi-institutional aspect of the course is something that should be encouraged in other elements of the overall training program.

The next logical element in the training of graduate students is a full degree program in bioacoustical oceanography. It was suggested that one approach to such a program might include having students, regardless of home institution, traveling to other institutions for portions of their graduate education. A multi-institutional education of this type, although unconventional, would offer the following benefits:

1) Students would be exposed to greater expertise in a variety of subject areas critical to their education as bioacoustical oceanographers;

2) Students would develop a sense of belonging to a closely-knit network of well-trained bioacoustical oceanographers; and

3) Students might be supported through a training grants program that would be independent of their home institution.

After graduate school, there is a critical need to support the new or continued training of postdoctoral fellows in bioacoustical oceanography. It was recommended that a postdoctoral program in bioacoustical oceanography be initiated within the biological oceanography section at NSF comparable to the one recently initiated in biotechnology. It was further suggested that NOAA and ONR be encouraged to support similar postdoctoral programs.

At the level of the working professional, mechanisms must be developed so that basic as well as advanced training in bioacoustical oceanography becomes more readily available. Short-term (1-2 week) workshops may meet some of these needs, but a longer term (0.5-1 year) "mentorship" program might be necessary for those professionals interested in retooling themselves as independent, competent practitioners of bioacoustical oceanography. NOAA, NSF, and ONR appear to be the most appropriate funding sources to support professional training grants and fellowships of this nature.

7. Summary and Recommendations

In addition to the recommendations documented in the individual working group reports, several common themes evolved from the meeting.

- It was recognized that development, acquisition, and use of new sampling technology was needed to successfully address GLOBEC science issues. Acoustical and optical technologies were acknowledged as leading candidates from which the necessary tools could be drawn to support the pursuit of GLOBEC's science goals.

- Based on their quasi-continuous sampling characteristics, acoustical and optical tools deployed in various ways (e.g., towed or hull-mounted sensors vs. moored, bottom-mounted, or drifting sensors) are essential to relating small-scale processes important at the level of the individual to large-scale processes that impact populations. This concept was described as "nesting" of sensors that measure small-scale temporal and spatial phenomena within measurements at incrementally increasing temporal and spatial scales up to those that include populations and their dynamics.

- Several groups stressed the importance of the mode of deployment of any acoustical, optical, or integrated sensor package. The same mode is not, in general, appropriate for all the different kinds of GLOBEC science questions. The ability to use an instrument in a diversity of deployment modes, e.g., cast, towed, hull-mounted, bottom-moored, etc., was considered a valuable sensor characteristic, substantially enhancing the usefulness of a particular instrument.

- Each of the working groups recognized the value of examining the same distribution of animals with more than one frequency of sound. It was recognized that the range and numbers of frequencies required depends on the sizes of the animals present, which animals present are of interest, their abundances, their physical characteristics, their distribution, and the mode in which the sensor is to be used.

- Several groups noted that modularity, standardization of instrumentation, and simplicity of operation and deployment were important. At the same time, arguments for versatility, flexibility in deployment mode and signal processing algorithms, sophisticated internal data processing, and low cost were presented. On the surface some of these criteria seem conflicting, thus requiring thoughtful tradeoffs when designing instrumentation.

- It was determined that the integration of acoustical and optical technology could yield synergistic benefits and that the technologies are complementary. Acoustic sensors could place optical measurements in the context of larger scale biological distributions. They may also be used to detect rare organisms that may prey on the relatively small and more numerous animals under study with the optical system. Acoustic sensors could also contribute data on vertical migration and swimming behavior to aid in better understanding optical observations. Optical data could provide important measurements of animal orientation, provide independent information on particle size spectra, and offer a potential for taxonomic identification of acoustically sensed individuals and distributions (e.g., aggregations, schools, patches, layers).

- There was a strong sense that sampling of both the biological environment (e.g., with acoustics and/or optics) and the physical environment (temperature, salinity, light, currents, turbulence, etc.) should be done synoptically rather than serially. There was also a sense that traditional methods will remain important in sampling the marine environment, but that the use of alternative sensors will result in major improvements in the efficiency of these conventional sampling tools.

- The establishment of data archiving protocols to facilitate long term (10's of years) use of data is explicitly recognized as a particular problem for acoustical data as it is for GLOBEC data in general.

- In some cases, access by the community of biological oceanographers to complex bioacoustic instrumentation is limited by acquisition cost and the multidisciplinary talents (electronics, acoustics, and machine level programming) required to operate, calibrate, adapt, and maintain such gear. The establishment and staffing of a limited number of "facilities" or "teams" to provide and maintain bioacoustic devices for data collection under the direction of individual or groups of investigators, is recognized as a viable approach to expansion of the biological communities' access to such devices.

- Finally, there was a consensus that there was a need for continued basic research and development in order to advance the state-of-the-art in remote underwater sensing of marine animals. Specifically, advances would be welcomed in the following areas:

    1) Development of new methods for quantitative combination of multifrequency acoustic data;

    2) Continued analytical research and supporting measurements directed towards the development of better and more comprehensive descriptions of acoustic scattering from all marine genera (e.g., adult fish, larval fish, micronekton, macrozooplankton and small zooplankton); and

    3) Development and validation of methods for quantitative combination of multisensor data (i.e., data fusion).

8. Acknowledgments

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Thanks are also due Ken Foote, for his overview of acoustic techniques, acoustic terminology and fisheries acoustics. Charles Greenlaw described the history and state of the art in acoustic assessment of mesopelagic animals. Doug Sameoto provided an update on the acoustic sampling of euphausiids and some interesting comments on comparison of acoustic and net sampling technologies. Van Holliday described techniques for assessing the abundance and distribution of small zooplankton. Alex Herman provided an overview of optical techniques including an excellent description of the optical particle counter. Gus Paffenhöfer contributed additional information on optical techniques with a recording of the swimming and feeding behavior of small zooplankton.

We also appreciate the invaluable participation of our colleagues who came from Canada (Doug Sameoto, Alex Herman, Yvan Simard and Len Zedel), Norway (Ken Foote) and Scotland (John Simmonds).

Lew Incze, Gordie Swartzman and Mark Ohman served as rapporteurs for the working groups and assisted the working group chairmen in the preparation of this report. We would also like to thank Chuck Greene for leading the panel discussion with Steve Brandt and Rudi Strickler on educational opportunities.

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9. References and Bibliography

Andersen, N.R. and B.J. Zahuranec (Eds.). 1977. Ocean sound scattering prediction. Plenum Press, New York.

Anderson, V.C. 1950. Sound scattering from a fluid sphere. J. Acoust. Soc. Am. 22: 426-431.

Arnone, R.A., R.W. Nero, J.M. Jech and I. De Palma. 1990. Acoustic imaging of biological and physical processes within Gulf Stream meanders. Eos 71: 982.

Balls, R. 1948. Herring fishing with the echometer. J. Cons. Int. Explor. Mer 15:193-206.

Baraclough, W.E., R.J. Lebrasseur and O.D. Kennedy. 1969. Shallow scattering layer in the subarctic Pacific Ocean: Detection by high frequency echosounder. Science 166: 611-613.

Bary, B. McK. 1966a. Backscattering at 12 kc/s in relation to biomass and numbers of zooplanktonic organisms in Saanich Inlet, British Columbia. Deep-Sea Res. 13: 655-666.

Bary, B. McK. 1966b. Quantitative observations of scattering of 12 kc/s sound in Saanich Inlet, British Columbia. Deep-Sea Res. 13: 667-677.

Beamish, P. 1971. Quantitative measurements of acoustic scattering from zooplankton organisms. Deep-Sea Res. 18: 811-822.

Castile, B.D. 1975 Reverberation from plankton at 330 KHz in the Western Pacific. J. Acoust. Soc. Am. 58: 972-976.

Clay, C. 5. 1983. Deconvolution of the fish scattering PDF from the echo PDF for a single transducer sonar. J. Acoust. Soc. Am. 73:1989-1994.

Clay, C.S. and H. Medwin. 1977. Acoustical oceanography: Principles and Applications. Wiley-Interscience, New York.

Craig, R.E. and S.T. Forbes. 1969. Design of a sonar for fish counting. FiskDir. Skr. Ser. HavUnders. 15: 210-219.

Costello, J.H., R.E. Pieper and D.V. Holliday. 1989. Comparison of acoustic and pump sampling techniques for the analysis of zooplankton distributions. J. Plankton Res. 11: 703-709.

Duvall, G.E. and R.J. Christiansen. 1946. Stratification of sound scatterers in the ocean. J. Acoust. Soc. Am. 20: 254.

Ehrenberg, J.E. 1972. A method for extracting the fish target strength distribution for acoustic echoes. Proc. IEEE mt. Conf. Eng. Ocean Environ. 1: 61-64.

Ehrenberg, J.E. 1974. Two applications for a dual beam transducer in hydroacoustic fish assessment systems. Proc. 1974 IEEE Int. Conf. Eng. Ocean. Environ. 1: 152-155.

Ehrenberg, J.E. 1979. A comparative analysis of *in situ* methods for directly measuring the acoustic target strength of individual fish. IEEE 3. Ocean. Eng. OE-4: 141-152.

Ehrenberg, J.E. 1983. A review of *in situ* target strength estimation techniques. FAO Fish. Rep. 300: 90-95.

Ehrenberg, J.E. 1989. A review of target strength estimation techniques. *In:* Y. T. Chan (Ed.), Underwater Acoustic Data Processing, pp. 161-176. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Ehrenberg, J.E., T.J. Carlson, J.J. Traynor and N.J. Williamson. 1981. Indirect measurement of the mean acoustic backscattering strength of fish. J. Acoust. Soc. Am. 69: 955-962.

Ehrenberg, J.E. D.W. Lytle. 1972. Acoustic techniques for estimating fish abundance. IEEE Trans. Geosci. Electron. 10: 138-145.

Ehrenberg, J.E., P.H. Wiebe, W.H. Hanot, H.G. McMichael and R.T. Miyamoto. 1989. BIOSPAR, a buoy system for acoustic monitoring of biological populations. Oceans '89, 4, Mar. Tech Soc. and IEEE, Seattle, WA, 1032-1035.

Everson, I., J.L. Watkins, D.G. Bone and K.G. Foote. 1990. Implications of a new acoustic target strength for abundance estimates of Antarctic krill. Nature 345: 338-340.

Eyring, C.F., R.J. Christiansen and R.W. Raitt. 1948. Reverberation in the sea. J. Acoust. Soc. Am. 20: 462-475.

Falk-Petersen, S. and A. Kristiansen. 1985. Acoustic assessment of krill stocks in Ullsfjorden, north Norway. Sarsia 70: 83-90.

Farmer, D.M. and R.D. Huston. 1988. Novel application of acoustic backscatter to biological measurements. *In:* B.J. Rothschild (Ed.), Toward a Theory on Biological-Physical Interactions in the World Ocean, pp.599-614. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Farquhar, G.B. (Ed.). 1971. Biological Sound Scattering in the Ocean. Proc. Int. Symp. Maury Center Ocean Sci., Washington, DC.

Flagg, C.N. and S.L. Smith. 1989a. On the use of the acoustic doppler current profiler to measure zooplankton abundance. Deep-Sea Res. 36: 455-474.

Flagg, C.N. and S.L. Smith. 1989b. Zooplankton abundance measurements from acoustic doppler current profilers. Oceans '89, Mar. Tech Soc. and IEEE, Seattle, WA, 4:1318-1323.

Foote, K.G. 1987. Fish target strengths for use in echo integrator surveys. J. Acoust. Soc. Am. 82(3): 981-987.

Foote, K.G., A. Aglen and 0. Nakken. 1986. Measurement of fish target strength with a splitbeam echo sounder. 3. Acoust. Soc. Am. 80(2): 612-621.

Forbes, S. and 0. Nakken. 1972. Manual of methods for fisheries resource survey and appraisal. Part 2. The use of acoustic instruments for fish detection and abundance estimation. FAO Man. Fish. Sci. 5:138 pp.

GLOBEC. 1988. Global Ocean Ecosystem Dynamics. Joint Oceanogr. Inst., Inc., Washington, DC.

GLOBEC 1991a. Theory and Modeling in GLOBEC: A First Step, February 1991, Joint Oceanogr. Inst., Inc., Washington, DC.

GLOBEC 1991b. Initial Science Plan, GLOBEC Report Number 1, February 1991, Joint Oceanogr. Inst., Inc., Washington, DC.

GLOBEC 1991c. Northwest Atlantic Program, Canada/U.S. Meeting on N.W. Atlantic Fisheries and Climate, GLOBEC Report Number 2, February 1991, Joint Oceanogr. Inst., Inc., Washington, DC.

GLOBEC 1991d. Workshop on Biotechnology Applications to Field Studies of Zooplankton, GLOBEC Report Number 3, February 1991, Joint Oceanogr. Instit., Inc., Washington, DC.

Goodman, N.R. 1965. Measurement of matrix frequency response functions and multiple coherence functions. Tech. Rept. AFFDL-TR-65-56, Air Force Flight Dynamics Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. NTIS Document Center No. AD *619995*.

Greene, C.H., T.K. Stanton, P.H. Wiebe and S. McClatchie. 1991. Acoustic estimates of Antarctic krill. Nature 349:110.

Greene, C.H., P.H. Wiebe and J. Burczynski. 1989. Analyzing zooplankton size distributions using high-frequency sound. Limnol. Oceanogr. 34:129-139.

Greene, C.H., P.H. Wiebe, R.T. Miyamoto and J. Burczynski. 1991. Probing the fine structure of ocean sound-scattering layers with ROVERSE technology. Limnol. Oceanogr. 36:193-204.

Greenlaw, C.F. 1979. Acoustic estimation of zooplankton populations. Limnol. Oceanogr. 24: 226-242.

Greenlaw, C.F. and W.G. Pearcy. 1985. Acoustical patchiness of mesopelagic micronekton. J. Mar. Res. 43:163-178.

Greenlaw, C.F., and R.K. Johnson. 1983. Multiple-frequency acoustical estimation. Biol. Oceanogr. 2: 227-252.

Harden-Jones, F.R. and B.S. McCartney. 1962. The use of electronic sector-scanning sonar for following the movements of fish shoals: sea trials on RRS Discovery II. J. Cons. Int. Explor. Mer 27:141-149.

Helstrom, C.W. 1968. Statistical Theory of Signal Detection. Permagon Press, New York, 470 pp.

Herman, A.W. 1988. Simultaneous measurement of zooplankton and light attenuance with a new optical plankton counter. Cont. Shelf Res. 8: 205-221.

Herman, A.W. and T.M. Dauphinee. 1980. Continuous and rapid profiling of zooplankton with an electronic counter mounted on a "Batfish" vehicle. Deep-Sea Res. 27: 79-96.

Hersey, J.R. and R.H. Backus 1954. Sound scattering by marine organisms. *In:* M.N. Hill (Ed.), The Sea, Vol.1. Interscience, New York.

Hewitt, R.P., P.E. Smith and J.C. Brown 1976. Development and use of sonar mapping for pelagic stock assessment in the California Current area. Fish. Bull. 74 (2): 281-300.

Holliday, D.V. 1972. Resonance structure in echoes from schooled pelagic fish. J. Acoust. Soc. Am. 51(4): 1322-1334.

Holliday, D.V. 1974. Doppler structure in echoes from schools of pelagic fish. J. Acoust. Soc. Am. 55(6): 1313-1322.

Holliday, D.V. 1977. Extracting biophysical information from the acoustic signatures of marine organisms. *In:* N.R. Anderson and B.J. Zahuranec (Eds.), Oceanic Sound Scattering Prediction, pp.619-625. Plenum Press, New York.

Holliday, D.V. 1980. Use of acoustic frequency diversity for marine biological measurements. *In:* F.P. Diemer *et al.* (Eds.), Advanced Concepts in Ocean Measurements for Marine Biology, pp.423-460. Univ. South Carolina Press, Columbia, SC.

Holliday, D.V. 1985. Active acoustic characteristics of nekton. *In:* J.W. Foerster (Ed.), The Biology and Target Acoustics of Marine Life, pp.115-144. U.S. Naval Academy.

Holliday, D.V. and R.E. Pieper. 1980. Volume scattering strengths and zooplankton distributions at acoustic frequencies between 0.5 and 3 MHz. J. Acoust. Soc. Am. 67(1): 135-146.

Holliday, D.V. and R.E. Pieper. 1988. Applications of underwater acoustics to the study of micronekton and zooplankton. *In:* M.F. Thompson and M.N. Tirmizi (Eds.), Proc. Int. Conf. on Mar. Sci of the Arabian Sea, AIB 5, pp.77-86.

Holliday, D.V., R.E. Pieper, C.F. Greenlaw and J.K. Dawson. 1990. Acoustic assessment of zooplankton in the Irish Sea, C.M. 1990/L: 17, 78th Statutory Meeting of the International Council for the Exploration of the Sea (ICES), October 6, 1990, 40 pp.

Holliday, D.V., R.E. Pieper and G.S. Kleppel. 1989. Determination of zooplankton size and distribution with multi-frequency acoustic technology. J. Cons. Int. Explor. Mer 41: 226-238.

Johnson, M.W. 1948. Sound as a tool in marine ecology, from data on biological noises and the deep scattering layer. J. Mar. Res. 7: 443-458.

Johnson, R.K. 1977a. Sound scattering from a fluid sphere revisited. J. Acoust. Soc. Am. 61: 375-377.

Johnson, R.K. 1977b. Acoustic estimation of scattering layer composition. J. Acoust. Soc. Am. 61:1636-1639.

Kalish, J.M., C.F. Greenlaw, W.G. Pearcy and D.V. Holliday. 1986. The biological and acoustical structure of sound scattering layers off Oregon. Deep-Sea Res. 33(5): 631-653.

Kristensen, A. and J. Dalen. 1986. Acoustic estimation of size distribution and abundance of zooplankton. J. Acoust. Soc. Am. 80: 601-611.

Lawson, C.L. and R.J. Hansen. 1974. Solving Least Squares Problems. Prentice-Hall, Englewood Cliffs, New Jersey, 340 pp.

Leih, T. and D.V. Holliday. 1982. Uniqueness of the non-negative least squares solution in the bioacoustic inverse problem. Tracor Document No. T-81-SD-026-U, 34 pp.

Love, R.H. 1969. Maximum side aspect target strength of an individual fish. J. Acoust. Soc. Am. 46: 746-752.

Macaulay, M.C. 1978. Quantitative acoustic assessment of zooplankton standing stock. PhD Thesis, Univ. Washington. 149 pp.

MacLennan, D.N. and S.T. Forbes, 1984. Fisheries acoustics: A review of general principles. Rapp. P.-v. Cons. Int. Explor. Mer 184: 7-18.

Maclennan, D.N. and E.J. Simmonds. 1991. Fisheries Acoustics. Chapman and Hall, London, 336 pp.

Marine Zooplankton Colloquium I. 1989. Future marine zooplankton research: A perspective. Mar. Ecol. Prog. Ser. 55:197-206.

Midttun, L. and 0. Nakken. 1971. On acoustic identification, sizing and abundance estimation of fish. FiskDir. Skr. Ser. HavUnders. 16: 36-48.

Mitson, R.B. 1983. Fisheries Sonar, Fishing News Books Ltd., Farnham, Surrey, England, 287 pp.

McNaught, D.C. 1968. Acoustical determination of zooplankton distributions. Proc. 11th Conf. Great Lakes Res. 1968: 76-84.

Nakken, 0. and K. Olsen. 1977. Target strength measurements of fish. Rapp. P.-v. Reun. Cons. Int. Explor. Mer 170: 52-69.

Northcote, T.G. 1964. Use of a high-frequency echosounder to record distribution and migration of *Chaoborus* larvae. Limnol. Oceanogr. 9: 87-91.

Paffenhöfer, G.A., T.B. Stewart, M.J. Youngbluth and T.G. Bailey. 1991. High resolution vertical profiles of pelagic tunicates. J. Plankton Res. (In Press).

Peterson, M.L., C.S. Clay and S.B. Brandt. 1976. Acoustic estimates of fish density and scattering function. J. Acoust. Soc. Am. 60: 618-622.

Pieper, R.E. 1979. Euphausud distribution and biomass determined acoustically at 102 KHz. Deep-Sea Res. 26: 687-702.

Pieper, R.E. and D.V. Holliday. 1984. Acoustic measurements of zooplankton distributions in the sea. J. Cons. Int. Explor. Mer 41: 226-238.

Pieper, R.E., D.V. Holliday and G.S. Kleppel. 1990. Quantitative zooplankton distributions from multifrequency acoustics. J. Plankton Res. 12: 433-441.

Price, H.J., G.A. Paffenhöfer, C.M. Boyd, T.J. Cowles, P.L. Donaghay, W.M. Hamner, W. Lampert, L.B. Quetin, R.M. Ross, J.R. Strickler and M.J. Youngbluth. 1988. Future studies of zooplankton behavior: Questions and technological developments. Bull. Mar. Sci. 43: 853-872.

Rayleigh, Lord. 1945. Theory of Sound. Second Edition. Dover Publications, New York. 984 pp.

Richter, K.E. 1985a. Acoustic scattering at 1.2 MHz from individual zooplankters and copepod populations. Deep-Sea Res. 32:149-161.

Richter, K.E. 1985b. Acoustic determination of small-scale distributions of individual zooplankters and zooplankton aggregations. Deep-Sea Res. 32:163-182.

Sameoto, D.D. 1976. Distribution of sound scattering layers caused by euphausiids and their relationship to chlorophyll a concentrations in the Gulf of St. Lawrence estuary. J. Fish. Res. Brd. Can. 33: 681-687.

Sameoto, D.D. 1980. Quantitative measurements of euphausiids using a 120-KHz sounder and their *in situ* orientation. Can. J. Fish. Aquat. Sci. 37: 693-702.

Sameoto, D.D. 1982. Zooplankton and micronekton abundance in acoustic scattering layers on the Nova Scotian slope. Can. J. Fish. Aquat. Sci. 39: 760-777.

Sameoto, D.D., L.O. Jaroszynski and W.B. Fraser. 1980. The BIONESS -- new design in multiple net zooplankton samplers. J. Fish. Res. Bd. Can. 37: 722-724.

Simard, Y., R. de Ladurantaye and J.C. Therriault. 1986. Aggregation of euphausiids along a coastal shelf in an upwelling environment. Mar. Ecol. Prog. Ser. 32: 203-315.

Smith, K.L., Jr., D. Alexandrou and J.L. Edelman. 1989. Acoustic detection and tracking of abyssopelagic animals: description of an autonomous split-beam acoustic array. Deep-Sea Res. 36:1427-1441.

Stanton, T.K. 1985a. Density estimates of biological sound scatterers using sonar echo peak

PDFs. J. Acoust. Soc. Am. 78(5): 1868-1873.

Stanton, T.K. 1985b. Volume scattering: Echo peak PDF. J. Acoust. Soc. Am. 77(4): 1358-1366.

Stanton, T.K. 1988. Sound scattering by cylinders of finite length. I. Fluid cylinders. J. Acoust. Soc. Am. 83: 55-63.

Stanton, T.K. 1989a. Sound scattering by cylinders of finite length. III. Deformed cylinders. J. Acoust. Soc. Am. 86: 691-705.

Stanton, T.K. 1989b. Simple approximate formulas for backscattering of sound by spherical and elongated objects. J. Acoust. Soc. Am. 86:1499-1510.

Stanton, T.K. 1991. Sound scattering by spherical and elongated shelled bodies. J. Acoust. Soc. Am. (In Press).

Stanton, T.K. and C.S. Clay. 1986. Sonar echo statistics as a remote-sensing tool: volume and sea floor. IEEE J. Ocean. Eng. OE-11: 79-96.

Stanton, T.K., R.D.M. Nash, R.L. Eastwood and R.W. Nero. 1987. A field examination of acoustical scattering from marine organisms at 70 kHz. IEEE J. Ocean. Eng. 12: 339-348.

Strickler, J.R. 1977. Observations of swimming performances of planktonic copepods. Limnol. Oceanogr. 22:165-170.

Sund, 0. 1935. Echo sounding in fisheries research. Nature 135: 956.

Traynor, J. J. and J.E. Ehrenberg. 1979. Evaluation of the dual beam acoustic fish target strength measurement method. J. Fish. Res. Brd. Can. 36:1065-1071.

Traynor, J. J. and J.E. Ehrenberg. 1987. Fish and standard sphere target strength measurements obtained with a split beam-dual beam system. Proc. Int. Symp. Fish. Acoust., Seattle, 1987. (In Press).

Van Leer, J.C., W. Duing, R. Erath, E. Kennelly and A. Speidel. 1974. The Cyclesonde: An unattended vertical profiler for scalar and vector quantities in the upper ocean. Deep-Sea Res. 21: 385-400.

Weston, D.E. 1967. Sound propagation in the presence of bladder fish. *In:* V.M. Albers (Ed.), Underwater Acoustics, Vol.2, Chap. 5, pp.56-88. Plenum Press, New York.

Wiebe, P.H., K.H. Burt, S.H. Boyd and A.W. Morton. 1976. A multiple opening/closing net and environmental sensing system for sampling zooplankton. J. Mar. Res. 34: 313-326.

Wiebe, P.H., C.H. Greene and T.K. Stanton. 1990. Sound scattering by live zooplankton and micronekton: empirical studies with a dual-beam acoustical system. J. Acoust. Soc. Am. 88: 2346-2360.

10. Glossary of Terms

Active Acoustics—A subdiscipline of the branch of physics that deals with the man-made generation, propagation, and scattering of sound projected into a medium (e.g., air, water or the earth) by an investigator for the purpose of remotely determining some characteristic of the transmission medium along the propagation path.

Acoustic Doppler Current Profiler (ADCP)—An acoustic sensor that measures the Doppler shift of acoustic scatterers in the water column and estimates the magnitude and direction of the 3-D motions of the "water" versus depth using the assumption that the scatterers are passive tracers of the water mass.

Acoustic echo—A pressure (or its representation in voltage) signal that results from the scattering of sound from an acoustic impedance discontinuity (target) in the medium in which the sound is propagating (e.g., an "echo" from a zooplankter or a school of fish). (Also see "Target".)

Acoustic Resolution, Resolved—In space, the minimum distance between two objects for which an active acoustic system can determine that there are two, rather than one, objects present. In frequency, the minimum separation between two frequency components (e.g., tones or lines) for which an analysis system can distinguish the presence of both frequency components. Objects or frequency components are said to be resolved, when there is sufficient precision in the measurement to separate the objects or components into distinguishable entities. The criteria for when this is the case may vary, depending on the characteristics of the system and the intended use of the information. The Rayleigh resolution criteria from geometric optics is often, but not uniformly, applied.

Acoustic scattering—The diversion of sound energy from its original direction of propagation.

Acoustic scattering models—A mathematical expression used to describe the sound scattering process from "targets" (e.g., marine organisms). Models range in complexity from empirically based linear regressions of acoustic scattering on size for a particular acoustic frequency, to complex expressions based on first principles of physics, the acoustic frequency, and the organism's shape, size, morphology, physical structure, compressibility, and density contrasts with the surrounding medium and the target's relative orientation with respect to the acoustic sensor.

Acoustic signatures—Any set of characteristics used to describe a sound signal, including echoes from "targets", radiated, and ambient noise. For an echo, the signature might include target strength, spectral reflectivity versus frequency, doppler shift, doppler spread, or target range extent (size).

Acoustic size classes—A term that loosely refers to acoustic estimates of the relative or absolute abundance of "targets" of different sizes. The degree with which the "acoustic size" matches the physical size depends on the accuracy of the mathematical model one uses to transform from the acoustic measurements to the estimated physical dimensions of the scatterers.

Acoustic tag—These devices, which are typically attached to fish, have also been used to detect and track whales and crabs. They come in at least two types. One is an instrument that periodically transmits a sound, allowing one to detect that sound at a remote location, determining the presence of the animal and its direction. The transponding acoustic tag makes a sound only when interrogated, thereby saving battery power in the tag and extending the tag life. By using the time delay between the interrogating signal and the reception of the acoustic response, the range to the animal can be estimated as well as its direction. Information about the animal, such as its depth or heart rate, can be encoded into the signal on either the simple or transponding tag.

Amphipod—Any of the relatively common and numerous small crustaceans of the order *Amphipoda.* Often found in assemblages of marine zooplankton.

Anthropogenic—Related to man's activities; man-made or caused by man.

Attenuation—Reduction in acoustic intensity experienced by a signal in transit between two spatially separated points. Parameters that contribute to attenuation include absorption, scattering, refraction (multiple paths), and geometric spreading.

Automatic gain control (AGC)—A form of signal processing used to maintain the amplitude of electrical signals within preset bounds. Signals are amplified or attenuated according to some measure of their amplitude or intensity, often by the mean square, or root mean square amplitude.

Backscattering cross-section—The ratio of the acoustic power scattered at an angle of 180 degrees from the incident acoustic wave, referenced to a stated unit distance, e.g., 1 m, to the acoustic intensity incident on a unit volume or unit area. This measure is the ratio of the reflected acoustic power to incident acoustic power/area, giving rise to units of area (m^2) for backscattering cross-section.

Bandwidth—The frequency range spanned by an acoustic or electronic signal of interest to the investigator (or used by an acoustic instrument). For some common types of acoustic signals (CW pulses), the acoustic bandwidth is inversely related to the pulse length of the pulse (ping) length.

Batfish—A towed body, used as an instrument platform, which can be actively controlled in depth by manipulation of its control surface. Often used to make measurements in a "tow-yo" mode along a transect. (See, e.g., Herman and Dauphinee, 1980)

Beam—Many acoustic systems either transmit or receive sound preferentially in some direction, either vertically or horizontally. The intensity of sound transmitted or the response to sound arriving at a sensor, as a function of angle around a preferred direction, defines an acoustic "beam". Roughly analogous to the light "beam" transmitted from a flashlight or the angle of acceptance of light in a telescope.

Beamforming—Measures taken to focus sound in a particular direction. Three typical means of beamforming include placement of a reflector (e.g., a cone or parabola) behind an acoustic source; phasing of narrowband signals emitted or received by an array of transducers or transducer elements; and shifting replicas of signals emitted or received by individual elements in such a way as to maximize the acoustic response in some direction. Can also refer to processing of data from the elements of an array to reject information from a particular direction.

Beamwidth—The angular extent around a maximum response axis within which the signals are some percent of the response in the direction of the maximum. The half (maximum) power points are often taken as the limit for the purpose of defining the beamwidth.

Bent cylinder models—Mathematical algorithms that describe the acoustic scattering from various classes of cylinders which have been characterized as having a radius of curvature along their length. (See, e.g., Stanton, 1989a, b.) Their proposed use has been to characterize and understand the magnitude, directionality, and mechanisms that give rise to acoustic scattering from zooplankton such as euphausiids and shrimp.

Bioacoustic, bio-acoustics—Refers to the use of acoustic technology to study plants or animals. Bioacoustics, as used in this document, refers to applications involving animals in the marine environment. It may employ either active or passive acoustic technology. Bioacoustics is also employed in the terrestrial environment, for example, in the detection of insects in grain and especially with the vocalizations of numerous species, such as apes, birds, and insects.

Biomass—A measure of the quantity of living material, usually in units of weight per unit volume.

BIONESS—A multiple net system with the capability of opening and closing nets on command from the surface in order to sample different depth strata on a single tow. (See Sameoto, *et al.,* 1980.)

Calibration—In this document, calibration refers to the process of establishing the sensitivity of an acoustic sensor or system to an acoustic stimulus and to the quantitative relationship between the electrical and acoustical parameters of an acoustic system. In acoustics, calibrations are expressed in absolute terms, with units that are traceable to the National Institute for Standards and Technology (e.g., meters, seconds, kg, etc.) or some comparable source of standards. In the strict sense, an experiment that compared a net haul with echo integrator outputs from an acoustic system would not be a calibration, rather it would be a comparison. A calibration on a stable acoustic system is deterministic, repeatable, and does not depend in any way on the population under study. A valid calibration allows absolute comparisons between different equipments and different investigators based on widely accepted physical or electronic standards (e.g., source level 212 dB // 1µPa or beamwidth = 14.22 degrees). The word calibration is often misused in bioacoustics when substituted for the word comparison. (See Comparison.)

Classification—In acoustic remote sensing, one can often quantify some set of characteristics associated with a "target" or sound scattering organism, school or aggregation. Examples are quantitative measurement of single frequency reflectivity or target strengths, reflectivity spectra (reflectivity versus frequency), location in the water column, geographic location, time of the year, target size, motion characteristics, etc. Other measures may be qualitative, e.g., compact, dispersed, weak, strong, layer-like, etc. From the entire set of remote measurements ("classification clues"), one can sort the detected acoustic contacts (targets) into "classes" with similar or identical characteristics. If enough is known about the possible set of targets present, this "classification" may lead to an "identification" with some probability and confidence level.

Coherence—A mathematical algorithm expressing a quantitative measure of the spatial or temporal relationships between two or more parameters. Simple coherence is the ratio of the square of the absolute magnitude of the cross spectral density function between two parameters and the product of the power spectral densities for each individual parameter. (For a generalized definition of coherence, including multiple and partial coherence, see Goodman, 1965.)

Comparison—The process of relating acoustic measurements (e.g., volume backscattering or echo integrator outputs) to the biomass or numerical abundance of some organism or assemblage of species. A regression between a series of biomass measurements from a net haul and the values of a comparable series of echo integrator values (or derived quantities) is a comparison -- not a calibration (See Calibration).

Confocal Imaging—An optical technique that uses a source point and a confocal point to image an object. The source and image point are scanned to produce a multi-dimensional image. Advantages of this technique for oceanographic optical imaging are a large reduction in backscattered light.

Copepod—An important component of the zooplankton consisting of at least 4,500 pelagic species, order *Calanoida* and *Cyclopoida.* Minute "shrimplike" organisms which range between about 0.05 and 10 mm in length. A major food for fish, these animals often dominate the marine zooplankton biomass.

Crustacean—Primarily marine, this class of zooplankton consists of about 26,000 species. It is characterized by a thin, chitinous exoskeleton.

CritterCam [R]—A camera system using an IR diode laser that was developed by J.R. Strickler

CTD—An instrument that measures conductivity, temperature, and depth.

Cyclosonde—A device that can be used as a platform for a variety of instruments, it profiles the water column by alternately rising to the surface and sinking. The device rises and sinks by adjusting the package buoyancy in a programmed manner (See Van Leer, *et al.,* 1974).

Density—In underwater acoustics and in bioacoustics, when discussing target strengths or acoustic characteristics of animals, the term usually refers to the mass per unit volume of an animal or some part thereof, given in kg/m^3. When discussing volume scattering strengths, the usage may refer to abundance, i.e. $numbers/m^3$.

Deconvolution—Mathematically a procedure or calculation that is used to remove the influence produced in a data set by a known system response function. For applications involving the removal of the effects of beam patterns from measurements of target strengths of fish, see Clay, 1983 and Stanton and Clay, 1986.

Detected, detection—This term and its variants have at least two meanings, one involving the calculation of the envelope of an acoustic signal or its analog or digital electronic waveform. In the context of the current report the word is used to mean identified as separate from a noise field in which it is usually embedded. Helstrom, 1968 is a good reference text on detection theory.

Doppler sonar—An acoustic instrument that measures the change in the acoustic frequency of the scattered sound or echo from that of the transmitted pulse. The magnitude and direction of the shift in frequency is related to the relative motion of the sensor and the scatterer.

Doppler shift/spread, spectrum width—The Doppler shift of an echo is the change in the mean frequency of an echo from the mean frequency of the acoustic signal originally transmitted into the water by an acoustic system. When the scattering is from acoustic reflectors (e.g., fish in a school) that are moving with different speeds or directions in relation to the location of the sensor, then each echo will have a different Doppler shift. If different parts of an individual are moving with different velocity components in the direction of the sensor or the relative velocity changes during a measurement (pulse length), then the signal spectrum will be distorted or spread. When the echoes are added together, the result will be a distribution of energy around some mean frequency. The width of the energy distribution is termed the Doppler spread or spectrum width of the echo. Not all of the spectral spread or width is necessarily due to motion, however, since each finite length waveform has a characteristic shape, independent of the Doppler effect.

Drifters—Originally developed to measure currents, this term refers to oceanographic instruments whose path is determined by the sum total of the forces imparted by wind, waves, and currents, i.e., they drift. Physical oceanographers have collectively put significant energy into minimizing the effects of wind and waves in attempting to design instrument platforms to follow particular "water parcels" in Lagrangian studies.

Dual-beam method—A technique for comparing echo voltage differences received on coaxial narrow- and wide- beams of an echo sounding or sonar system to determine whether the target is near the principal axis of the coaxial beams, assuring that the measurement of the target strength of an organism is near the point of maximum (known) response of the beam (e.g., see Traynor and Ehrenberg, 1979). This allows one to place approximate bounds on the acoustic system related measurement errors associated with estimates of the ratio of incident to reflected acoustic intensity from the target of interest, i.e., its target strength.

Echo—A distinct acoustic signal resulting from the reflection of sound from an object.

Echogram—A form of display used to present acoustic data from an echo sounder. Originally, a strip of treated paper moved by a vertically rotating stylus which marked signals detected by the echo sounder on the paper electrically. The rate of the movement of the stylus down the paper was proportional to the speed of sound in the water. Echoes from near the surface appeared near the top of the paper and echoes from deeper in the water column appeared nearer the bottom of the paper record. More modern versions present the same basic kind of display electronically on a computer display or CRT. Colors are sometimes used in this case to encode echo amplitude or some other acoustic characteristic of the echo (e.g., doppler shift).

Echo integrator, echo integration—An electronic instrument or software package which sums echo intensities over a time interval to estimate echo energy. Used in quantifying the scattering from schools of fish or plankton in bioacoustics. (For example, see Forbes and Nakken, 1972 or Mitson, 1983)

Echo sounder—An acoustic system which produces (usually) short acoustic pulses, transmits them into the water column vertically and then detects echoes from impedance discontinuities (e.g., fish, the bottom, or plankton) and displays the result to an operator. Originally used to "sound" for the bottom for navigation purposes, the technique was adapted for use by fishery biologists by Balls (1948) and refined by successive investigators. It is extensively used by fishermen to locate fish and by fisheries scientists to assess fish populations when the data are quantitatively process by techniques such as echo integration.

ESD—The Equivalent Spherical Diameter is the diameter of a sphere of the same volume as the particle or animal being described.

ESR—The Equivalent Spherical Radius is the radius of a sphere of the same volume as the particle or animal being described.

Eulerian—For the purposes of this report, Eulerian methods measure processes and/or water properties at points in a coordinate system fixed to the earth.

Euphausiid—Common "shrimplike" marine crustaceans which grow to as much as 8 cm in length, many species of which migrate vertically in the water column. These animals are known to occur in dense shoals and patches. Euphausiids, or krill, are an important component of many marine food chains. Adult euphausiids are sufficiently good swimmers that they are considered by some investigators to be micronekton.

Expendable Acoustic Profiler (EAP)—A low cost active acoustic sensor concept for assessing zooplankton that could be employed (especially from the air) in remote areas such as the Antarctic, where it is costly to send surface research vessels. The device would be expendable, telemeter data to an aircraft and be somewhat analogous to an AXBT.

Fine-scale, fine structure—Structure in any ocean feature or parameter with energy in the spatial range from about 1 meter to about 100 meters.

Fish larvae—Post-egg, but pre-juvenile fish.

Fluid sphere model—A mathematical description of the spatial scattered acoustic field around a spherical object whose density, compressibility, or both contrast with that of the surrounding medium. This model, first developed by Anderson (1950) and several variations have been widely used to describe scattering from zooplankton in the sea. Its popularity, while having some basis in a proven utility for describing some zooplankters and assemblages of small plankton, is also partly due to its relative analytical tractability and simplicity.

Fluorescence—In the context of this document, the emission of red light by chlorophyll (and phaeopigments) in phytoplankton when stimulated by ultraviolet light. The effect is used to obtain an index of abundance of phytoplankton.

Food web—The interrelated food relationships in an ecosystem.

Frequency—In acoustics, the rate at which an periodic event, e.g., the upward "zero crossing" of a pressure waveform, occurs in time. Frequency is the inverse of the period of a signal. The period is the time interval between two identical points on a repetitive waveform.

Gelatinous zooplankton—Examples include salps, larvaceans, medusae, and ctenophores. These "jellylike" organisms have neither an exoskeleton nor an endoskeleton. Occasionally found in extremely high concentrations.

Geoacoustics—A sub-discipline of geophysics which uses sound reflection and propagation to study the subsurface structure of the terrestrial and marine environments.

Geometric scattering—Acoustic scattering in which the wavelength of the sound used is much smaller than the size of object causing the scattering.

Georges Bank—A relatively shallow, biologically productive, oceanographic area located off the northeast coast of the United States.

GLOBEC—Global Ocean Ecosystems Dynamics

Holographic Imaging—A method which uses interferometric techniques to record the interference pattern between an object in 3-D and a reference wave. By shining a laser through the recording medium, usually a film, a virtual image of the object can be seen. By focusing the reconstructed image at different planes, a three dimensional volume can be scanned.

Hydrophone—An underwater microphone. This term describes an acoustic transducer that receives sound and converts acoustic pressure to an analogous electrical signal.

Identification—In applications of acoustics to biological issues, usually reserved for association of a remotely sensed organism with a genera or species. For example, the vocalization of a marine mammal or bird may lead to a unique determination of the species.

Inversion method, algorithm, technique—Any mathematical process which, in the context of this workshop report, estimates some property or combination of properties of the ocean environment from observed characteristics acoustic scattering or propagation in the sea. This is in contrast to "forward" calculations, which assume or measure the ocean properties and calculate the characteristics of the acoustic parameters one can sense. In most instances, in this document, reference to inverse methods, means the calculation of the abundance and/or sizes of acoustically sensed organisms. The mathematics of many of the inverse methods used in bioacoustics were adapted from some other field, e.g., geophysics, space technology, or medical research.

Imaging, 3-D—Remote sensing that produces a three dimensional "picture" or analogous display of an object or some property of an object within a volume, e.g., the acoustic impedance map of an object or group of objects. One technique uses a sound beam, which may be focused or scanned to interrogate different look directions as a function of time (or simultaneously with multiple beams). The analysis of the backscattered information can be used to discern the position as well as other features of animals in the three dimensional field of view.

IR diode laser—A solid state electronic device that is a source of collimated, narrowband light in the infrared part of the optical spectrum.

JGOFS—Joint Global Ocean Flux Study.

JOI—Joint Oceanographic Institutions Inc.

kHz—The abbreviation for kilohertz, this refers to the units of electronic or acoustic frequency (one thousand cycles per second).

Krill—Norwegian term for euphausiids, originally referring to the North Atlantic species *Meganyctiphanes norvegica, Thysanoessa inermis,* and occasionally *T. raschii.* The term is often used to refer to other species of euphausiids that aggregate in dense swarms or patches.

Lagrangian—Measurements in a Lagrangian coordinate system imply that water properties or biological processes are measured while following the mean flow of a water parcel, e.g., from a drifter.

Laser rangegated imaging—An optical technique which synchronizes the firing of a laser and the opening of a camera shutter after a precise time delay. The method can be used to circumvent optical backscatter limitations of traditional imaging as well as to collect information about only a thin slab of targets at a specific range from the camera and light source.

Macrozooplankton—Large (e.g., cm size) plankton that have significant swimming capabilities. An example might be *Euphausia superba.* Usage varies among different communities.

MAPS—Multifrequency Acoustic Profiling System - Holliday *et al.*, 1989; Pieper and Holliday, 1984.

MBARI—Monterey Bay Aquarium Research Institute

Mesopelagic—Referring to mid-depths in the open ocean.

Mesoscale—Oceanic features with scales on the order of 100 to 300 km.

MHz—The abbreviation for megahertz, this is the units of frequency (one million cycles per second).

Micronekton—A transition term commonly used to describe those animals in the "fish" that are small in size, but can effectively swim in the presence of at least moderate currents. Usage varies among different communities. (Also see macroplankton.)

Micropascal (μPa)—A unit of pressure equal to one millionth of a newton per square meter.

Micro-scale, microstructure—Spatial structure in any ocean feature or parameter with energy at dimensions of less than about 1 meter.

MOCNESS—A multiple net system for sequentially sampling zooplankton at different depths or collecting serial samples at the same depth (see Wiebe, *et al.*, 1976.)

Mysid—Pelagic or demersal crustaceans of the order *Mysidaceae.* These organisms are known to swarm and occur both in freshwater lakes and in the marine environment.

Nekton—Aquatic organisms that can effectively swim against relatively strong horizontal currents, e.g., adult fish of many species.

NMFS—National Marine Fisheries Service

NOAA—National Oceanographic and Atmospheric Administration

NSF—National Science Foundation

ONR—Office of Naval Research

Open architecture—A form of instrument or "smart" sensor in which there is planned access to hardware, firmware, or software which allows the "user" to modify or adapt the operating characteristics to fit special circumstances and needs.

Ping—A pulse or other acoustic signal of finite temporal duration introduced into the water by an acoustic system, usually for the purpose of echo ranging on an object (target), detecting its presence, determining its location, and classifying or identifying it.

Planar sonar array—A group of acoustic transducers, arranged in some pattern on a plane for the purpose of converting sound into electrical signals or vice versa.

Plankton Image Analyzer—A device developed at URI/NMFS-Narrragansett to enumerate samples of zooplankton from their recorded images and classify individuals into taxonomic groups.

Rayleigh scattering—Scattering of a propagating wave, in our case acoustic, when the dimension of the region or object which is causing the scattering is much less than the wavelength of the ensonifying sound.

Reverberation—Acoustic energy reflected from all of the distributed, and often randomly located, scatterers in the path of an acoustic wave. Consists of returns from the surface, inhomogeneities in the volume and the bottom. A dominant characteristic of reverberation is the stochastic nature of the signal, thus multiple samples (pings) must be averaged in order to obtain estimates of the strength of the process.

ROV—Remotely Operated Vehicle

Sea Beam—An acoustic system usually used by the geophysics community to acquire multibeam bathymetry. Has also been used to a limited extent to examine volume scattering.

Shadowgraph—A side-scan sonar with exceptionally high spatial resolution.

SIO/MPL—Scripps Institution of Oceanography, Marine Physical Laboratory

Size-frequency distribution—Histograms, tables, plots or other displays of the abundance of organisms versus size. Sometimes called "size-abundance distributions" in papers on bioacoustics to minimize confusion with alternate uses of the word "frequency" (See the definition of Frequency, above.)

Small zooplankton—For the purposes of this workshop and this document, the term "small zooplankton" was taken to mean zooplankton for which some variant of the fluid sphere scattering model is an appropriate (or at least approximate) mathematical description of the scattering process. This is in contrast to, for example, adult euphausiids, for which there is evidence that alternate models are better descriptors of the scattering process.

Sonar—Originally an acronym that stands for **So**und **Na**vigation and **R**anging. In hydroacoustics, it has come to mean an active acoustic sensor which uses a propagation path to the target organisms, school or aggregation that is dominantly horizontal as opposed to an echo sounder, where the propagation path for the sound is principally vertical.

Split-beam method—A multibeam target strength measurement technique that uses the phase relationships of a target in the various beams to estimate the location of target and therefore beam pattern correction in the composite beam (see Foote, *et al.,* 1986.)

Target—A target is an inhomogeneity in the surrounding medium (in underwater acoustics, the water), which reflects sound and has finite bounds in relation to the physical volume sampled by the acoustic system with which the entity was detected. The manifestation of the reflection process is an "echo". This is in contrast to "reverberation", which is the result the reflection of sound from a zone or volume with indefinite size, at least insofar as the measurement system can distinguish.

Target strength—A measure of the reflectivity of an acoustically detected entity with defined physical bounds (fish, plankter, fish school, etc.). Technically, it is ten times the common logarithm of the ratio of the incident intensity of a sound wave of distant origin to the intensity reflected in some specified direction, referred to a fixed reference distance, usually 1 meter from the target's "acoustic center". The target strength usually depends on the size, shape and internal structure of the sound scatterer, the frequency used in the acoustic system, and the contrast of the physical properties of the target material with the surrounding medium.

Tilt angle—For fish, in particular, the angle at which the animal is ensonified (usually near dorsal aspect for echo sounders) will affect the target strength one would wish to use in estimating the biomass in a layer or school. If a species swims with other than a horizontal orientation (on the average), the tilt angle, or deviation from the horizontal, should be known in order to make an accurate biomass estimate.

Thermistor—An electronic resistor which has a known dependence on temperature. The change in resistance is used to measure the temperature of the surrounding medium.

Tomographic methods—Mathematical techniques for reconstructing three dimensional volumes from the integrated projections along rays. In medical imaging tomography, x-rays are used to determine the x-ray attenuation coefficient inside of the body. This can then be related to anatomy. Potential uses in oceanography encompass both light and acoustic tomography.

Transducer—In acoustics, a device that is used to convert acoustic energy to electrical energy or vice versa. There are several distinct technologies that are commonly used to accomplish this task.

Triangulation—In general, the unique location of the source of a sound (or echo) from some combination of at least three ranges and/or bearings in three dimensional space.

Trophic levels—Successive stages of nourishment as represented by links of the food chain.

Underwater Acoustics, Hydroacoustics, Fisheries Acoustics—A branch of physics involving the generation, propagation, scattering and reception of sound in the marine environment. The term hydroacoustics is sometimes used in place of underwater acoustics, especially in the fisheries acoustics community.

Video Plankton Recorder (VPR)—A towed video camera system under development at WHOI which is intended to sample on centimeter scales over many kilometer transects.

V-fin—A specially shaped towed body whose hydrodynamics produce a net force downward. Shaped in "end-on" cross section like an inverted "V" or "U", it can be used as a depressor for another body or net system, or as a platform for an oceanographic instrument or sensor such as an acoustic transducer.

Volume reverberation—Acoustic scattering from randomly positioned particles, organisms or other random acoustic impedance discontinuities in the water column. Characterized by the stochastic nature of the acoustic signal, most volume reverberation is of biological origin.

Volume scattering strength—Ten times the common logarithm of the ratio of the acoustic intensity scattered through 1800 from a unit volume (e.g., 1 m^3) at a specified reference distance (e.g., 1 m) to the incident plane wave intensity. Usually written S_V

WHOI—Woods Hole Oceanographic Institution

Zooplankton—Aquatic animals whose horizontal movements are largely subject to local water currents. While the word plankton originated from the Greek work "drifter", many zooplankters are good swimmers. They do not have the option of changing geographic locations over large distances, however, without resorting to such tactics as vertical migration to position themselves in favorable currents.

11. Appendices

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Acoustical Technology and the Integration of Acoustical and Optical Sampling Methods

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11.3 Appendix C- Meeting Agenda

GLOBEC
Acoustical Technology Workshop
Woods Hole, MA
April 2 - 4, 1991

Tuesday April 2

0900	Welcome and Logistics	Peter Wiebe Tim Stanton
0910	GLOBEC Program Overview	Eileen Hofmann
0945	Atlantic Project	Mark Huntley
1020	Pacific Project	Mark Ohman
1105	Break	
1120	Antarctic Project	Mark Huntley
1135	Arabian Sea Project	Sharon Smith
1210	Lunch	
1315	Fisheries Acoustics	Ken Foote
1355	Mesopelagic Fish Acoustics	Charles Greenlaw
1425	Euphausiid Acoustics	Doug Sameoto
1500	Break	
1515	Acoustics & Small Zooplankton	Van Holliday
1550	Optical & Acoustical Technology	Alex Herman
1640	Organization of Working Groups	Van Holliday
1650- 1700	Meeting of Working Group Chairmen	

Wednesday, April 3

0830-1200	Working Group Discussions	
	Zooplankton Acoustics	Rick Pieper
	Macrozooplankton/Micronekton Acoustics	Tim Stanton
	Fisheries Acoustics	Jim Traynor
	Acoustical *I* Optical Sensor Integration	Peter Ortner
1330-1700	Working Group Discussions (continued)	

Thursday. April 4

0800-0930	Working Groups (finalize individual reports)	
0930-1030	Group Discussion: Educational and Training Opportunities in Bio-acoustical and Bio-optical Oceanography	Chuck Greene Steve Brandt Rudi Strickler
1030-1045	Report of Working Group on Zooplankton Acoustics	
1045-1100	Report of Working Group on Macrozooplankton & Micronekton Acoustics	
1100-1115	Report of Working Group on Fisheries Acoustics	
1115-1130	Report of Working Group on Acoustical & Optical Sensor Integration	