Advanced Multi-Frequency Inversion Methods for Classifying Acoustic Scatterers

Duncan E. McGehee
BAE SYSTEMS
4669 Murphy Canyon Road, San Diego, CA 92123
phone (858) 268-9777 fax (858) 268-9775 duncan.mcgehee@gcccd.net

Mark C. Benfield
Louisiana State University, Coastal Fisheries Institute
Wetland Resources Bldg, Baton Rouge, LA 70803
phone: (225) 578-6372 fax: (225) 578-6513 email: mbenfie@lsu.edu

Charles F. Greenlaw
BAE SYSTEMS
4669 Murphy Canyon Road, San Diego, CA 92123
phone (858) 268-9777 fax (858) 268-9775 charles.greenlaw@baesystems.com

D. V. Holliday
BAE SYSTEMS
4669 Murphy Canyon Road, San Diego, CA 92123
phone (858) 268-9777 fax (858) 268-9775 van.holliday@baesystems.com

Contract Number: N00014-00-D-0122, Award Number: N00014-01-1-0305
http://zooplankton.lsu.edu/scattering_models/MultifreqInverseMethods.html

LONG-TERM GOALS

The goals of this study are to develop species- and life-stage-specific acoustic scattering models based on morphologically-accurate digitizations of preserved or live-imaged zooplankton from coastal waters. These models will estimate scattering strength as a function of acoustical frequency, animal size, taxon, and orientation relative to the incidence angle. These predictions will improve our ability to estimate animal abundances by taxon/morphological class via inversion.

OBJECTIVES

1) Develop lists of commonly occurring zooplankton species and life-stages as functions of the time of year for the Georges Bank/Gulf of Maine and the northern Gulf of Mexico;

2) Obtain representative images of taxa from the species lists using data from the Video Plankton Recorder, other video sources, photos of living and dead specimens, and scientific illustrations;

3) Develop acoustic scattering models based on digitized image; and

4) Provide methodology and model data to the oceanographic community via the world-wide-web.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Advanced Multi-Frequency Inversion Methods for Classifying Acoustic Scatterers**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **BAE Systems,,4669 Murphy Canyon Road,,San Diego,,CA, 92123**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

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

APPROACH

Acoustical scattering models of zooplankton have generally been developed by modeling target taxa as relatively simple geometric shapes. As our understanding of scattering models has improved, there has been a progression towards the use of higher resolution, more anatomically correct scattering models (e.g. Stanton and Chu, 2000). Our approach follows this direction and we are attempting to develop models of scattering derived from digitizations of actual zooplankton shapes. These shapes will be derived from both *in situ* video images and preserved samples. One of the advantages of this approach is that orientation data can frequently be derived from *in situ* images of plankton (e.g. Benfield *et al*. 2000). Knowledge of the orientations of zooplankton may be critical in predicting scattering because the target strength can vary substantially depending upon the angle of incidence of the acoustic wave relative to the orientation of the animal.

This is a collaborative project between LSU and BAE SYSTEMS. LSU is collecting the various images of zooplankton and developing lists of dominant taxa by season for our study areas while BAE SYSTEMS and LSU are digitizing the images and developing the scattering models.

At the inception of this project we planned to use VPR data from the Gulf of Maine/Georges Bank region collected during cruises undertaken during October 1997; October and December 1998; and October and December 1999. We selected these data because these cruises contained concurrent, VPR and multi-frequency acoustic data collected by the BIOMAPER II vehicle, punctuated by MOCNESS samples. Data from the Gulf of Mexico included 1m^2 net samples collected in the summer of 2000 approximately 50 km SW of the Mississippi River along with SEAMAP zooplankton records. The latter were to be used to estimate seasonal periodicity.

WORK COMPLETED

We have assembled large numbers of potentially suitable VPR images of a variety of zooplankton taxa. The majority of these were digitized directly from the VPR tape recorded during cruise EN331 during December 1999. These images were evaluated by McGehee at BAE SYSTEMS who concluded that the images lacked sufficient detail to use as a basis for digitization of morphologically accurate silhouettes.

While the VPR dataset will provide essential data on *in vivo* orientation, we turned to preserved samples of zooplankton collected with the 1m^2 MOCNESS for higher resolution morphological data. Dr. Peter Wiebe at Woods Hole Oceanographic Institution has begun digitizing silhouette photographs (Ortner *et al*. 1979) of zooplankton collected in our study area. These high-resolution (1200 dpi) images appear well suited for development of morphological silhouettes (Fig. 1). Even small copepods contain sufficient detail to resolve their shapes. We have completed digitization of a variety of copepod taxa from silhouette or other microscope-derived images. A very high resolution, large format scanner at LSU has been adapted to scan samples of zooplankton collected in the Gulf of Mexico so that they can be digitized in the same manner as the Gulf of Maine samples.

The digitized images of copepods have been used to develop models of acoustical scattering based on the DWBA model (Stanton *et al*. 1998) as a function of size, orientation, and acoustical frequency. The methodology used to create the models, example data, and results have been published in a publicly accessible website that allows users to view images and data of scattering models for taxa we have analyzed. In addition, the site allows users to create their own scattering models for taxa and sizes that may be of particular interest. In the future, models created by users will be incorporated into the site database. The URL for the site is:

http://zooplankton.lsu.edu/scattering_models/MultifreqInverseMethods.html

Figure 1. [Left] 7" x 9" silhouette photograph of a MOCNESS zooplankton sample that has been digitized at 1200 dpi. [Right] Close up of the highlighted region in the large silhouette containing a single medium-sized copepod surrounded by small copepods.

RESULTS

Images of zooplankton derived from VPR surveys generally lacked sufficient detail to provide useful digitizations of zooplankton from which to derive scattering models. The reason appears to be the relatively low resolution of the VPR images (72 dpi). Nevertheless, these images have value because they provide essential information on typical orientations and postures of live zooplankton. High-resolution scans of preserved zooplankton provide sufficient detail to create scattering models. In addition, an atlas of marine and estuarine zooplankton from the Gulf of Maine (Gerber, 2000) has just been published and it contains detailed line drawings of many of the taxa of interest in this study and has been used to supplement the silhouette-based models. We have completed the analysis of the taxa summarized in Table 1. These include taxa from the Gulf of Maine/Georges Bank and the Ligurian Sea. We are currently adding taxa from these regions and from the northern Gulf of Mexico taxa.

An example of the process of creating a model for *Paraeuchaeta norvegica* illustrates the type of data that can be obtained using our methodology. The model began with a silhouette photograph of *P. norvegica* collected from a MOCNESS net in Jordan Basin during December 1999 (Fig. 2). The lateral view of the copepod in the silhouette image was rotated so that the long axis of the animal was horizontal and then the perimeter of the prosome and urosome was digitized in Matlab or NIH Image (Fig. 2). A three-dimensional representation of the 2D digitized two-dimensional profile was created assuming a circular symmetry about the centerline of the perimeter (Fig. 2).

A series of Matlab programs were used to calculate the target strength of the model at acoustical frequencies from 10 kHz to 5 MHz. At each frequency, we computed the backscattering amplitude f_{bs} 10,000 times using a randomly assigned angle of incidence. The average of the 10,000 f_{bs} estimates was used to estimate the mean backscattering amplitude and then TS at each frequency (Fig. 3).

Table 1. Summary of taxa for which DWBA models have been developed.

Gulf of Maine/ Georges Bank	**Other Regions**
Acartia tonsa	*Clausocalanus* sp. (Ligurian Sea)
Calanus finmarchicus (adult female)	*Corycaeus* sp. (Ligurian Sea)
Calanus finmarchicus (CV)	*Helectinosoma* sp.
Centropages typicus	*Oithona* sp.
Paraeuchaeta norvegica	

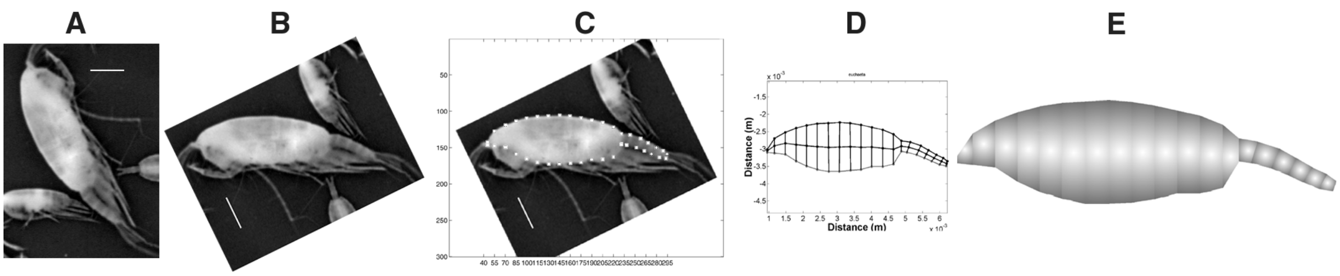

Figure 2. Steps in the development of a three-dimensional model of Paraeuchaeta norvegica. A. We begin with a silhouette photograph of the copepod from a MOCNESS tow. The white line is a 1mm scale bar. B. The image is rotated so that the copepod's long axis is horizontal. C. The image is brought into MATLAB and digitized at regular points along the prosome and urosome. D. The digitized points are scaled using the dimensions of the scale bar and plotted in 2D space. E. The midpoint of each section is used to create a 3D model assuming a circular symmetry about the centerline of each digitized section. Although this 3D representation appears to have segmentation, it is an artifact of the visualization and the actual model is a series of flat cylindrical sections.

IMPACT/APPLICATIONS

ONR has allocated significant resources to the development of both sophisticated acoustic scattering models and multiple-frequency systems such as TAPS and BIOMAPER II. This research is a logical extension in merging those two lines of research. The long-range goal of this research is to develop a method that can be tailored to any multi-frequency or broadband acoustic system to provide real-time classification of scatterers.

The goal of biological oceanographers is to be able to determine: (1) what organisms are present in a given ecosystem; (2) at what abundance levels the organisms are present; (3) how they are distributed;

and (4) what the factors are that control their abundances. This means we must be able to detect, count, and classify the organisms. There are currently three general ways of going about these tasks: nets and pumps, optics, and acoustics. Each of these has certain advantages and disadvantages. The present work seeks to integrate the data from acoustics and independent sampling systems to provide a better view of the distributions of animals in the oceans.

The presence, abundance and dynamics of life in the sea at all trophic levels have both direct and indirect impacts on the ability of MCM, ASW, undersea warfare, expeditionary warfare, and special operations forces to perform their missions. Zooplankton and micronekton in the water column can control the optical properties of interest through grazing on phytoplankton. They may also interfere with operational and planned Navy acoustic systems. Many zooplanktors are bioluminescent or influence the distribution and abundances of bioluminescent organisms at higher trophic levels. It has become increasingly important for the Navy to be able to know in real time what organisms are present in the water column and in what quantities. This study is aimed at directly assessing that need.

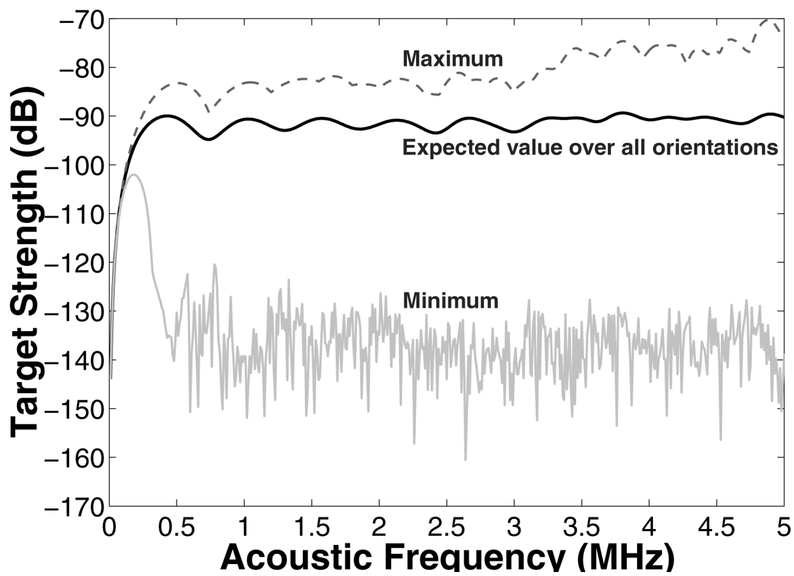

Figure 3. Acoustic target strength as a function of frequency (10 kHz steps, 0-5MHz) for the DWBA model of Paraeuchaeta norvegica. Each expected value is the average of 10,000 randomly selected angles of incidences. The maximum and minimum estimated values are also provided.

TRANSITIONS

We are in the process of attempting to integrate multi-frequency acoustic and optical data collected by the BIOMAPER II vehicle in the Gulf of Maine during 1997-1999. Comparisons of the datasets indicate relationships between acoustical scattering layers and the presence of individual zooplankton taxa. In collaboration with colleagues at the Woods Hole Oceanographic Institution, we are working to scale measured acoustic scattering into biomass distributions using existing scattering models and predicted abundances from the VPR (Benfield *et al*. Submitted). The techniques developed in this project will provide an alternative methodology for combining the information content of optics and acoustics to estimate taxon-specific distributions of zooplankton biomass in the water column.

RELATED PROJECTS

Project N00014-98-1-0563 “Development of a Vertically Profiling, High-Resolution, Digital Still Camera System” has produced an *in situ* optical profiling system called ZOOVIS. This camera system was deployed in Knight Inlet, BC in November 2001 as part of an ONR-funded project to examine aggregation of zooplankton near sills. ZOOVIS has potentially higher resolution than the VPR when imaging larger volumes and will likely generate images with sufficient detail as well as orientation information for incorporation into the present study.

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