# Work Term Report III

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# 1.0 Summary

This work term was completed under the supervision of Dr. Andone Lavery and Dr. Gareth Lawson in the Biology, and Applied Ocean Physics & Engineering Department at Woods Hole Oceanographic Institution. Assigned duties included the comprehension of concepts related to active acoustics, particularly Fourier transforms, acoustic scattering models, the forward problem and the inverse problem, identifying the source of the strong pervasive acoustic scattering layer observed in the northeast Pacific, developing MATLAB® skills to analyze the HammarHead EdgeTech broadband acoustic data, examining the size distribution of copepods and other organisms in the layer using Video Plankton Recorder (VPR) images and Multiple Opening/Closing Environmental Sensing System samples and performing a forward calculation. All duties were completed.

Zooplankton composition and size were determined using net sampling techniques, and water properties were determined using conductivity, temperature, and depth sensors. Dominant scatterers have been identified using scattering models for zooplankton. A scattering model for *Corolla* was also developed to determine their contributions to the total scattering. *Corolla,* and elastic-shelled pteropods, which both accounted for a small fraction of the total abundance and biomass, dominated the scattering at low and high frequencies, respectively. Fluid-like siphonophore body parts, which accounted for a small fraction of the total abundance, but a large fraction of the total biomass, dominated the scattering at mid frequencies. Contrarily to previous findings, copepods that accounted for most of the abundance, but little of the biomass, never dominated the scattering. The oceanographic characteristics of the locations analyzed may have created an ideal microenvironment for these organisms to aggregate in layers. Recommendations for future directions include focusing on the completion of analysis of other casts to compare data collected at various locations in addition to the development of comprehensive scattering models for *Corolla* and siphonophores.

All personal objectives set at the beginning of the work term were fulfilled. How these were completed throughout the work term is examined. An assessment of personal development and performance focuses on the effects of living in a small town and in a foreign country. Additionally, observations of the workplace regarding relationships within and outside the office with supervisors and co-workers, office politics, the important of self-confidence and assertiveness and other aspects of the work environment are presented. A comparison of work styles between the workplace and academic setting is also made.

The work term was of an appropriate difficulty level based on skills and previous experience. However, future co-op students should consider a similar work term only if they possess adequate programming and mathematical skills. Both academic and personal aspects of this work term far exceeded expectations. Not only will the research experience and skills acquired contribute to my future career success, but also the application of lessons learned from previous work terms has contributed to a greater sense of confidence. I sincerely hope to have the opportunity to work with Dr. Andone Lavery and Dr. Gareth Lawson in the future.

# 2.0 General Information About the Hiring Organization

## 2.1 Woods Hole Oceanographic Institution

Woods Hole Oceanographic Institution (WHOI) is a world-renowned non-profit ocean research institution based in Woods Hole, Massachusetts, United States of America. The institution has an annual operating budget of $215 million from government grants and contracts, foundation and private donations, and industry contracts. WHOI currently serves over 1,000 employees, and offers Ph.D. programs, and summer student and postdoctoral fellowships. Scientists at the institution study all aspects of the ocean including the coastal ocean, ocean life, deep ocean, and climate change. Additionally, WHOI operates research vessels *Atlantis* and *Knorr* as well as the coastal vessel *Tioga*.

## 2.2 Biology Department

With over 20 graduate students, the Biology Department has one of the largest graduate programs at Woods Hole Oceanographic Institution. More than 30 full-time scientists conduct research at all levels of biological organization, from molecules and cells to communities and ecosystems. Faculty members collectively seek to understand life in the oceans and the interactions of marine organisms with their environment. The research often involves collaborations with other WHOI scientists to understand the interactions of marine life with its chemical, physical, and geological surroundings. WHOI Biologists also collaborate with WHOI engineers in the development of novel instrumentation to enable improved sampling of marine organisms and gathering of data *in situ* and remotely. The department is committed to excellence in teaching and scholarship.

## 2.3 Applied Ocean Physics & Engineering Department

With only 11 graduate students, the Applied Ocean Physics & Engineering (AOPE) Department has one of the smallest graduate programs at Woods Hole Oceanographic Institution. More than 30 full-time scientists conduct research on ocean processes from the turbulent surf zone to the abyssal depths. The research encompasses air-sea interaction on local and global scales, mixing processes, sediment transport, estuarine and coastal hydrodynamics, ocean acoustics, underwater communication, internal waves, signal processing, mooring dynamics, and physical-biological processes. AOPE also builds and operates a group of underwater vehicles and instruments designed for ocean exploration including HOV *Alvin*, ROV *Jason*, and the AUVs *Sentry,* REMUS and SeaBED. The department is committed to excellence in teaching and scholarship.

### 2.4 Dr. Andone Lavery

Dr. Andone Lavery is an Associate Scientist with Tenure in the Applied Ocean Physics & Engineering Department at Woods Hole Oceanographic Institution. As a principal investigator, Dr. Lavery has been involved in research in the area of acoustical oceanography, that is, studying the physics and biology of the ocean, and their interactions, through the use and development of acoustic techniques. Her recent work has been focused on acoustic scattering by marine organisms, acoustic scattering from physical processes, and acoustic propagation in highly turbulent environments. Dr. Lavery was a co-supervisor for the work term.

### 2.5 Dr. Gareth Lawson

Dr. Gareth Lawson is an Associate Scientist in the Biology Department at Woods Hole Oceanographic Institution. As a principal investigator, Dr. Lawson has been involved in research that focuses on the interplay of physical and biological factors in determining variability in the distribution and movements of pelagic organisms, ranging from zooplankton to fish. His recent work has been focused on the impacts of ocean acidification on pteropods. Dr. Lawson was a co-supervisor for the work term.

## 3.0 Identifying the nature of a strong pervasive acoustic scattering layer in the northeast Pacific

The following is a copy of the final report submitted to Woods Hole Oceanographic Institution as a requirement for the Summer Student Fellowship. The report includes background information about the study, a detailed description of duties and techniques used, and study conclusions and recommendations. Professional learning objectives for this work term included the following:

1. Comprehension of concepts related to active acoustics, particularly Fourier transforms, acoustic scattering models, the forward problem and the inverse problem.
2. Identifying the source of the strong pervasive acoustic scattering layer observed in the northeast Pacific.
3. Developing MATLAB® skills to analyze the HammarHead EdgeTech broadband acoustic data.
4. Examining the size distribution of copepods and other organisms in the layer using Video Plankton Recorder (VPR) images and Multiple Opening/Closing Environmental Sensing System samples.
5. Performing a forward calculation.

As demonstrated by the report below, these objectives and many more unforeseen outcomes were completed. Recommendations of future directions for study and analysis are also included.

The most useful previously taken academic class for the work term was Physics Tools, Theory (PHYC 2140). This class provided an introduction to some of the basic mathematical and physics concepts needed to comprehend and present acoustic data, particularly Fourier transforms. However, a previous work term in the Department of Oceanography at Dalhousie University was the most useful experience during the work term. Programming experience in MATLAB® eliminated the learning curve associated with learning a programming language, and enabled the creation of complex tools that could be easily used for any universal data set. Recommended future classes include Introduction to Numerical Programming (PHYC 3050), Mathematical Methods of Physics (PHYC 4160) and Invertebrate Biology (MARI 3301). These classes would not only develop a student's mathematics skills, but also further prepare them for the identification of zooplankton.

# Identifying the nature of a strong pervasive acoustic scattering layer in the northeast Pacific

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Dr. Gareth Lawson, Department of Biology, Woods Hole Oceanographic Institution

## ABSTRACT

Both multi-frequency and broadband acoustic scattering techniques have been used to investigate the nature of a strong pervasive acoustic scattering layer observed during both day and night, at a depth of approximately 20-50 m in the northeast Pacific. Zooplankton composition and size were determined using net sampling techniques, and water properties were determined using conductivity, temperature, and depth sensors. Dominant scatterers have been identified using scattering models for zooplankton. A scattering model for *Corolla* was also developed to determine their contributions to the total scattering. *Corolla,* and elastic-shelled pteropods, which both accounted for a small fraction of the total abundance and biomass, dominated the scattering at low and high frequencies, respectively. Fluid-like siphonophore body parts, which accounted for a small fraction of the total abundance, but a large fraction of the total biomass, dominated the scattering at mid frequencies. Contrarily to previous findings, copepods that accounted for most of the abundance, but little of the biomass, never dominated the scattering. The oceanographic characteristics of the locations analyzed may have created an ideal microenvironment for these organisms to aggregate in layers.

## I. INTRODUCTION

Ocean acidification is the process by which the concentration of carbonate ion ($CO_3^{2-}$) and the pH of seawater have decreased due to the absorption of anthropogenic carbon dioxide ($CO_2$) from the atmosphere by the oceans (Doney *et al.*, 2009). Many questions remain concerning the ecological, societal and economic impact of ocean acidification. Particularly, it is likely that the decrease in carbonate concentration will have important implications to marine organisms that secrete calcium carbonate shells or skeletons (Fabry *et al.*, 2008; Reid *et al.*, 2009). The calcification rate in these organisms is expected to slow in response to ocean acidification (e.g., Riebesell *et al.*, 2000; Comeau *et al.*, 2009). Additionally, it is known that the compensation depth, where waters are corrosive to biogenic forms of calcium carbonate, is becoming increasingly shallow (Feely *et al.*, 2004; Orr *et al.*, 2005). Marine zooplankton communities that undergo diel vertical migration, wherein animals migrate to shallow depths during night to feed and return to deeper depths by day to avoid visual predators, will be greatly affected by the shallower saturation horizon (Frost and Bollens, 1992; Bollens *et al.*, 1994; Hays, 2003). It is currently unknown if these organisms can adapt physiologically or behaviourally to the present and expected changes in ocean carbonate chemistry (Orr *et al.*, 2009).

Unlike coral and coccolithophores, there have been far too few studies investigating the effects of ocean acidification on thecosome pteropods (Fabry *et al.*, 2008). Although these calcareous planktonic gastropod molluscs are important ecosystem members, little is known about their abundance, distribution, movements and ecological role. It is expected that ocean acidification will impact the calcification rates of thecosome pteropods (Orr *et al.*, 2005; Comeau *et al.*, 2009) in addition to their diel vertical migration patterns (Orr *et al.*, 2005, 2009; Ohman *et al.*, 2009).

Acoustics has long been used in studies of zooplankton ecology because it can provide sampling over multiple spatial and temporal scales (e.g., Wiebe *et al.*, 1996; Brierley *et al.*, 1998; Lawson *et al.*, 2004, 2008). Often coupled with net and video sampling to "ground-truth" measurements, sound can be used to estimate biologically meaningful quantities, such as animal abundance or size, from measurements of high-frequency volume backscattering (e.g., Holliday and Pieper, 1980, 1995; Wiebe *et al.*, 1997; Lawson *et al.*, 2004, 2006). Known as the “inverse problem,” there are still many inherent difficulties associated with the interpretation of the acoustic echoes.

In contrast to traditional narrowband active acoustic scattering techniques, emerging high-frequency broadband scattering techniques address some of these challenges by utilizing a continuous spectrum of scattering over a range of frequencies (Lavery *et al.*, 2010). Bioacousticians are able to discriminate amongst targets acoustically by capitalizing on the distinct frequency-dependent spectra of different scattering sources (e.g. Martin *et al*, 1996; Wiebe *et al.*, 1996; Lawson *et al.*, 2004; Lavery *et al.,* 2007). In general, plankton are divided according to three anatomical classes: fluid-like (e.g. euphausiids, copepods), gas bearing (e.g. siphonophores, fish) and hard elastic-shelled (e.g. planktonic gastropods, various benthic shells) (Stanton *et al.*, 1994, 1998a, b). Comparing the observed to the predicted volume scattering from these organisms allows dominant water-column scatterers to be identified (Lavery *et al.*, 2007). Known as the “forward problem”, this comparison is completed using physics-based scattering models that incorporate net and/or video measurements of animal size, shape and abundance. A comprehensive understanding of the expected level of scattering from individual organisms is required to use acoustics as a remote sensing tool for mapping the distribution and abundance of mixed zooplankton populations.

The primary objective of this investigation is to identify the source of a strong pervasive acoustic scattering layer observed during both day and night, at a depth of approximately 20-50 m in the northeast Pacific. A similar scattering layer was described by Barraclough *et al.* (1969) between depths of 20 and 40 m over most of the northern Pacific using a 200 kHz echosounder. This investigation employs a comprehensive array of instruments including optical, net, hydrographic, acoustic (including both multi-frequency and broadband echosounders), and carbonate chemistry sensors in order to determine the nature of the observed layer. As such, it is one of the first broad scale applications of a high-frequency broadband echosounder for the remote quantification of animal abundance.

Specific objectives include using video and net sampling techniques with scattering models to make forward predictions of expected backscattering and comparing this predicted volume backscattering with measured volume backscattering. This will facilitate the identification of the dominant scatterers in the layer and allow the distribution and variability of those scatterers to be deduced. It is hypothesized that Barraclough *et al.* (1969) incorrectly concluded that the strong pervasive acoustic scattering layer observed was composed, based on net tows, of 99% copepods, specifically *Calanus* (now *Neocalanus*) *cristatus*. Possible alternative sources of scattering include other macro zooplankton and microstructure.

# II. METHODS

## A. Study Area

This project was conducted as part of the Ocean Acidification Pteropod Study (OAPS), which strived to gain a better understanding about the impacts of ocean acidification on the ecological role of thecosome pteropods, as well as to develop and apply new acoustic techniques for the monitoring of these threatened organisms. Two inter-disciplinary cruises were conducted between 35 and 50°N: one transect in the northwest Atlantic aboard the R/V *Oceanus* from August 7 to September 1, 2011, and one in the northeast Pacific aboard the R/V *New Horizon* from August 9 to August 21, 2012 and August 26 to September 18, 2012 (Fig. 1 and 2). These transects were previously occupied WOCE/CLIVAR Repeat Hydrography transects (A20 in the Atlantic and P17N in the Pacific) and were chosen to profit from the availability of historical data. The cruises involved a combination of station-work and underway measurements with a comprehensive array of instruments including acoustic, video, net, hydrographic and carbonate chemistry sensors. Only selected data from the Pacific cruise are considered in this investigation.

## B. Acoustical sampling

### *1. Hydroacoustic Technology Inc. (HTI) multi-frequency echosounder*

Measurements of volume backscattering strength and target strength were made near-continuously along-track and on station with a hull-mounted Hydroacoustic Technology Inc. (HTI, Seattle, WA, USA) multi-frequency echosounder. Four split-beam transducers at 43, 120, 200 and 420 kHz looked to maximum ranges of 500, 300, 150 and 100 m, respectively. Acoustic data were collected with a 10 kHz bandwidth linear frequency modulated (chirp) pulse at a repetition rate of 1.78 pings/s. The vertical resolution of the data after processing was 1 m at all frequencies. Echo-integration was performed over all pings collected within 6-s intervals, corresponding to a horizontal resolution of approximately 15-20 m, depending on vessel speed. Even though the transducers operated reasonably well with respect to noise, a region of enhanced backscattering was observed at the surface for all frequencies during net tows. This echosounder was turned off while the HammarHead EdgeTech broadband acoustic system was collecting data.

### *2. HammarHead EdgeTech broadband acoustic system*

Measurements of volume backscattering strength were occasionally made at day-night stations with a heavily customized downward-looking towed broadband acoustic scattering system manufactured by EdgeTech Inc. (Boca Raton Branch, FL, USA). The system operated at six channels: A1 (35-70 kHz), A2 (80-120 kHz), LOW (120-200 kHz), MID (220-300 kHz), HL (300-450 kHz) and HH (450-600 kHz). Acoustic data were collected with a linear frequency modulated (chirp) pulse of 500 μs duration at a repetition rate of 0.5 pings/s. All channels were calibrated using frequency-dependent calibration curves, generated in a controlled laboratory tank before or after the field deployment. The HammarHead was deployed 10 to 20 m above layers of interests, identified by the HTI data. Since it was limited to a maximum range of 50-150 m depending on the frequency, the system was profiled vertically, and toward obliquely up and down through the water column.

## C. Physical sampling

CTD profiles were performed with a sampling frequency of 24 Hz. The CTD was mounted on a rosette equipped with 24 10 L Niskin bottles, CTD with dual temperature/conductivity sensors, a Digiquartz pressure sensor, a SBE43 dissolved oxygen sensor, a biospherical underwater photosynthetically active radiation (PAR) sensor with surface reference PAR, a Wet Labs C-Star transmissometer (660 nm wavelength), a Wet Labs ECO-AFL fluorometer and an altimeter was deployed at regular stations (every ½ degree of latitude) to 1000 m and at day-night stations (every 2 degrees of latitude) to 3000 m (Fig. 3). These hydrographic and carbonate chemistry measurements were used as key correlates of the distribution, abundance and species composition of sampled zooplankton. In addition, the CTD rosette casts were readily used to determine the calcium carbonate saturation state and carbonate compensation depth. Data were also collected continuously over most of the cruise with a Teledyne RD Instruments Ocean Surveyor Acoustic Doppler Current Profiling (ADCP) at a sampling frequency of 75 Hz.

## D. Biological sampling

### *1. Nets*

A standard 1-$m^2$ Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS; Wiebe *et al.*, 1985) was used to collect depth-resolved zooplankton samples at day-night stations, where one daytime and one night-time tow were performed (Fig. 4). The MOCNESS system was towed obliquely while the HTI multi-frequency echosounder was collecting acoustic data at the surface. The system was equipped with eight 150 μm mesh nets (nets 1-8) and one 333 μm mesh net (net 0) in addition to standard SeaBird temperature and conductivity probes (units #535 and #120, respectively). Further, the system also had a beta-type strobe-light unit to reduce avoidance of the nets by some nekton. The first net (net 0) sampled the water column from the surface down to approximately 1000 m. The remaining eight nets sampled the upper 50 m in 25 m intervals (nets 7 and 8), followed by a 50 m interval to 100 m (net 6), a 100 m interval to 200 m (net 5) and 200 m intervals to 1000 m (nets 1-4). For each net, half of the sample was preserved in 95% ethanol, a quarter was preserved in 5% formalin and a quarter was preserved in 70% ethanol upon recovery. The "silhouette" method developed by Ortner *et al.* (1979) and modified by Davis and Wiebe (1985) was used to measure the length of each individual organism in net samples saved in 5% formalin. If an excessively large number of organisms was present in a particular sample, samples were split into two equal portions, making it feasible to count every individual.

### *2. Video images*

A Video Plankton Recorder (VPR, Davis *et al.*, 1992), mounted under the CTD rosette, was used to describe the abundance and vertical distribution of plankton along the study transects. A high-magnification underwater video system was also used, however, the area imaged by the analog camera and strobe light was only 14 x 14 mm, many times smaller than the acoustic or MOCNESS sampling areas. Regions of interest that met user-defined criteria for size, focus and brightness were sorted into different taxonomic categories, enumerated and measured together with the location, time and depth at which they were observed (Benfield *et al.*, 1996; Benfield *et al.*, 2003; Davis *et al.*, 2004). Only the images collected during the continuous downcast were extracted.

## III. SCATTERING MODELS AND PARAMETERS

### A. Basic equations

The backscattering amplitude, $f_{bs}$, for an individual target relates the incident to backscattered sound and depends on the acoustic frequency, and the size, shape, orientation and material properties (i.e. density and sound speed contrasts) of the target (Stanton *et al.*, 1998b; Lavery *et al.*, 2007). Because of the large range of values spanned by the returned acoustic signals, acoustic backscattering is often expressed in terms of the target strength (TS), a measure of the proportion of the incident energy that is backscattered by the target with units of decibel (dB) relative to 1 $m^2$, which is given by

$$\mathrm{TS} = 10\log_{10}(\sigma_{\mathrm{bs}}) \,, \quad (1)$$

where

$$\sigma_{\mathrm{bs}} = |f_{\mathrm{bs}}|^2 \,, \quad (2)$$

is the differential backscattering cross section.

When the individual targets are very small and there are many in the sampled volume, their echoes combine incoherently to form a received signal (Lavery *et al.*, 2007). Although the individual targets can no longer be resolved, the echo intensity is still a measure of the biomass in the water column. The basic acoustic measurement is the volume backscattering coefficient ($s_v$) with units of $m^2/m^3$, which is given by

$$s_{\mathrm{v}} = \frac{\sum \sigma_{\mathrm{bs}}}{\mathrm{V}_0} \,, \quad (3)$$

where $\sum \sigma_{\mathrm{bs}}$ is the scattered echo energy from the aggregation of scatterers and $V_0$ is the scattering volume. The equivalent logarithmic measure is the volume backscattering strength,

$$S_v = 10\log_{10}(s_v) \,, \quad (4)$$

which has units of dB relative to an inverse meter.

## B. Acoustic scattering model for *Corolla*

*Corolla* are shell-less pteropods, with a large gelatinous slipper-like pseudoconch covered with warts and disc-shaped wings. In the analyzed MOCNESS sample, three sets of wings and twelve pseudoconchs were found. However, no previous studies have developed methods for discriminating *Corolla* scattering from that of other animals. Thus, as part of this investigation, an acoustic scattering model was developed for this genus to determine their contributions to the total scattering. A simple model assuming that *Corolla* scatter sound like a fluid sphere was used. Assuming that the volume of the spheres and the individual organisms are the same (Anderson, 1950), the total volume of an individual *Corolla* used to determine the equivalent spherical radius (ESR) was the sum of the displacement volumes for both the pseudoconch and the body. Material properties, i.e. the density of the sphere (g) and the sound speed within it (h) expressed as contrasts, were inferred from mean values for *Salpa thompsoni* determined by Wiebe *et al.* (2010).

## C. Predicting volume backscattering from zooplankton: The forward calculation

The predicted volume backscattering based on the MOCNESS samples was calculated using equation (3) at the four HTI multi-frequency echosounder frequencies ($f_q$ = 43, 120, 200 and 420 kHz). However, it was only calculated at the depth range of the seventh MOCNESS net, i.e. 25 – 50 m. The measured volume backscattering was averaged over the same range and time intervals as were sampled by the seventh MOCNESS net in order to compare the measured and predicted volume backscattering. Elevated scattering, probably due to bubbles generated by the deployment of the MOCNESS, was observed in the top 25 m of the water column. As this region influenced the measured backscatter below and is, thus, critically important in the comparison of the predicted volume backscattering with measured volume backscattering, volume backscattering values from the enhanced region were replaced with values from adjacent regions (Fig. 5).

## IV. GENERAL OBSERVATIONS IN THE NORTHEAST PACIFIC

### A. Acoustical observations

The volume scattering strength during the 2012 cruise of the northeast Pacific was characterized by a strong pervasive acoustic scattering layer, present during both day and night at a depth of approximately 20 to 50 m (Fig. 6). This layer was patchy and even weak or absent in some locations, but was overall highly persistent. At some locations and depths, for example at (43.112N, 138.166W), two distinct scattering layers were observed during the day, while only one distinct scattering layer was observed at nighttime (Fig. 7 and 8). At all times and in all observed layers, the scattering increased monotonically with frequency from 35 kHz to 300 kHz, but was broadly similar between 300 and 600 kHz (Fig. 9 and 10). High scattering levels were observed close to the sea surface, probably due to bubbles.

### B. Physical observations

A CTD profile was performed after each tow of the EdgeTech system. At (43.112N, 138.166W), the thermocline was located at approximately 25 m during both the day and night (Fig. 11 and 12). Throughout the sampling period, the halocline and pycnocline were considerably shallower than the thermocline at approximately 5 m. Peaks in fluorescence and oxygen always occurred slightly below the thermocline (Fig. 13 and 14).

### C. Biological observations

#### *1. Nets*

One daytime MOCNESS tow at (43.112N, 138.166W) has been analyzed for taxon composition and size distribution. Copepods and pteropods made up the majority of the numerical abundance of zooplankton at this location (Fig. 15). Yet, neither contributed significantly to the biomass (Fig. 15). Bracts of siphonophores made up the majority of the biomass, even though they were not particularly numerically abundant. Other weakly scattering zooplankton such as amphipods and chaetognaths, and euphausiids contributed significantly to the total biomass. Ctenophores, *Corolla*, forams, nectophores of siphonophores and other zooplankton were present in the sample, however they were not numerically abundant and made up an insignificant portion of the observed biomass at this location. No pneumatophores of siphonophores were observed in the sample.

### *2. Video images*

Video images collected by the VPR were not used to analyze taxon composition and size distribution. Images were indistinguishable likely due to poor operational settings and not due to poor postprocessing settings.

## V. DETERMINING DOMINANT SCATTERERS

In this section, predicted dominant biological scatterers (scatterers that make up more than 50% of the total predicted scattering) are identified based on the composition and size of zooplankton in MOCNESS net 7, tow 11 and compared to the measured multi-frequency backscattering data collected at the same time and location with the HTI multi-frequency echosounder towed at the surface. Scattering predictions are performed over the frequency range from 10 kHz to 600 kHz, for comparison with the four HTI frequencies within that range.

### A. Nets

The total predicted scattering of biological origin below 50 kHz and particularly at 43 kHz was strongly dominated by *Corolla* (Fig. 16 and 17). The predicted scattering based on *Corolla* alone was in relatively good agreement with measured scattering at all frequencies (Fig. 18). However, their relative contribution to the total scattering decreased with increasing frequency. Nectophores and bracts of siphonophores also contributed to the total scattering at this frequency. Between 50 and 150 kHz and particularly at 120 kHz, nectophores were now the dominant scatterers (Fig. 19), but the relative contribution to scattering from bracts had also increased. The relative contribution of both nectophores and bracts was greatest at this frequency. No one species dominated the scattering between 150 and 400 kHz. Yet, fluid-like siphonophore body parts were still the largest contributors to the total scattering at 200 kHz, with nectophores contributing approximately 35% and bracts contributing approximately 25% (Fig. 20). The predicted scattering based on nectophores and bracts alone was also in relatively good agreement with measured scattering at all frequencies, respectively (Fig. 18). Small contributions to the total scattering from euphausiids, pteropods and amphipods became apparent at this frequency. Overall, the predicted scattering between 400 and 600 kHz and particularly at 420 kHz was not dominated (i.e. was not >50% of the total predicted scattering) by a single taxon (Fig. 21). Pteropods were one of the main predicted scatterers at this frequency. As expected, the contribution to the total scattering from pteropods increased with increasing frequency. However, the predicted scattering based on pteropods alone under predicted the observed backscattering at all frequencies, especially at 43 and 120 kHz (Fig. 18). The contribution from nectophores at 420 kHz was only slightly smaller than that of pteropods. Although copepods were very abundant, their contribution to the total predicted scattering was not apparent at any frequency. In general, the relative contribution to the total predicted scattering from nectophores, bracts and *Corolla* decreased with increasing frequency, while the contribution from other fluid-like and elastic-shelled zooplankton increased.

## VI. DISCUSSION AND CONCLUSIONS

It was found that in the scattering layer investigated in this study, a single type of scatterer did not dominate the scattering at all frequencies. Instead, at frequencies below 50 kHz, low abundances of *Corolla* that did not contribute significantly to the overall biomass dominated the scattering. Conversely, high abundances of elastic-shelled pteropods that also did not contribute significantly to the overall biomass made a large contribution to the scattering at frequencies between 400 and 600 kHz. Between 50 and 150 kHz frequencies, low abundances of fluid-like siphonophore body parts that did contribute significantly to the overall biomass dominated the scattering. No one species dominated the scattering between 150 and 400 kHz. In contrast to Barraclough *et al.* (1969), there was little evidence that copepods were a significant contributor to volume backscattering. Barraclough *et al.* (1969) were probably able to observe scattering from copepods during their trans-Pacific crossings for a combination of reasons: 1) Their measurements were conducted during a different season (i.e. spring), 2) their measurements were performed in a more northern part of the Pacific, and 3) their measurements were conducted with much simple instrumentation, a single 200 kHz narrowband echosounder and simple net systems. Further, the total predicted spectrum was consistent with both the total multi-frequency and broadband spectrum. However, the magnitude of the spectra is incorrect likely because the scattering is predicted over a 30 m interval instead of a 1 to 2 m interval over which it is measured.

The acoustic identity of the layers did not change significantly between the top and bottom layer, nor between the two layers during the day and the one layer during the night at the location analyzed. This suggests that not all the organisms inhabiting this layer undergo diel vertical migration. Although it is known that some pteropods and copepods do undergo diel vertical migration (Be and Gilmer, 1977; Wormuth, 1981, 1985; Frost and Bollens, 1992; Bollens *et al.*, 1994; Nigro and Seapy, 2008), it is unknown if *Corolla* display this same behaviour. In addition, the uppermost acoustic layer observed during the day and the single acoustic layer observed at night occur at approximately the same depth as the thermocline. Thus, it is possible that the oceanographic characteristics of this location produced an optimal environment for organisms to aggregate. As the surface waters are warm (e.g. approximately 18 °C), and the peaks in fluorescence and oxygen occur slightly below where these acoustic layers were observed, this microenvironment may be ideal for these organisms and outweigh some of the benefits associated with moving to deeper depths to avoid predators.

Both the accuracy of the acoustic system and scattering models for interpreting the measured volume backscattering data is critical. First, errors in the calibration curves can lead to incorrect assumptions about the type of scatterers present in the water column (Lavery *et al.*, 2010). Initial calibrations used in this investigation utilized a mean value across the band for the HH channel. Using this calibration, the volume scattering strength decreased at higher frequencies for all spectra. However, using a frequency-dependent calibration curve acquired during the analysis, the volume scattering strength remained fairly constant. The importance of good calibrations curves cannot be understated. Second, the fluid-sphere theory used to model the scattering from *Corolla* is a poor approximation (Greenlaw, 1977; Johnson 1977; Pieper and Holliday, 1984; Stanton 1988a, 1990). The model does not take into account the irregular shape of this organism, nor does it take into account its orientation. Because it is difficult to accurately assess the abundance of these delicate organisms using net systems, comprehensive scattering models would allow accurate conclusions to be drawn about their relative abundance and biomass using only acoustics.

In conclusion, the nature of the strong pervasive acoustic scattering layer observed throughout the Pacific likely varies spatially and temporally. At the location analyzed in early September, *Corolla*, fluid-like siphonophore body parts and pteropods each dominated at different frequencies. Thus, no single type of scatterer dominated at all frequencies. Contrarily to findings by Barraclough *et al.* (1969), copepods, although abundant, did not dominate the scattering at any frequency.

## VII. FUTURE WORK

Future work should focus on the completion of the analysis of other casts at this location of interest in order to compare observations during the day and night. In addition, completion of the analysis of acoustical, optical, and net data for northern locations along the Pacific cruise track would allow for a better comparison to findings by Barraclough *et al.* (1969). User-friendly analysis tools (i.e. Matlab® code) would allow others to expand the scope of this investigation. Finally, comprehensive scattering models for *Corolla* and siphonophores would allow accurate conclusions to be drawn about their relative abundance and biomass using only acoustics.

## ACKNOWLEDGEMENTS

The author would like to thank Andone Lavery and Gareth Lawson for their invaluable guidance, support and feedback throughout this study. The author would also like to thank Nancy Copley for her assistance in developing silhouette images, and Jon Fincke and Robert Levine for generously providing their computer code for calculating spectra and volume backscattering, respectively. This research was supported in part by the NSF Ocean Acidification program (Grant # OCE-1041068) and the Summer Student Fellowship Program at Woods Hole Oceanographic Institution.

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**Figure 12** Conductivity, temperature, and depth (CTD) profile at 43.112N, 138.166W at night.

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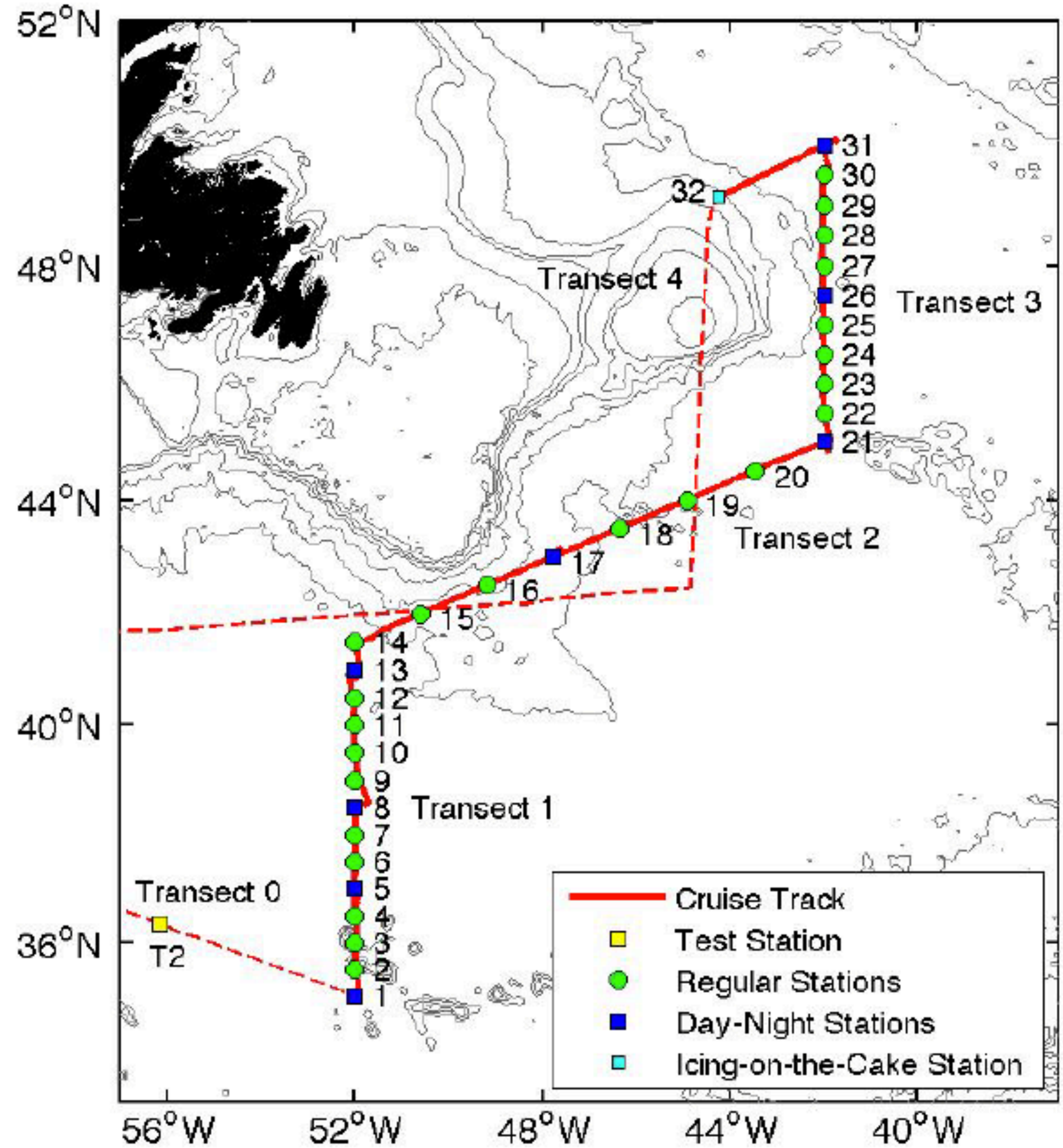

52°N
48°N
44°N
40°N
36°N
56°W
52°W
48°W
44°W
40°W
Transect 0
T2
Transect 1
Transect 2
Transect 3
Transect 4
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Cruise Track
Test Station
Regular Stations
Day-Night Stations
Icing-on-the-Cake Station

**Figure 1.**

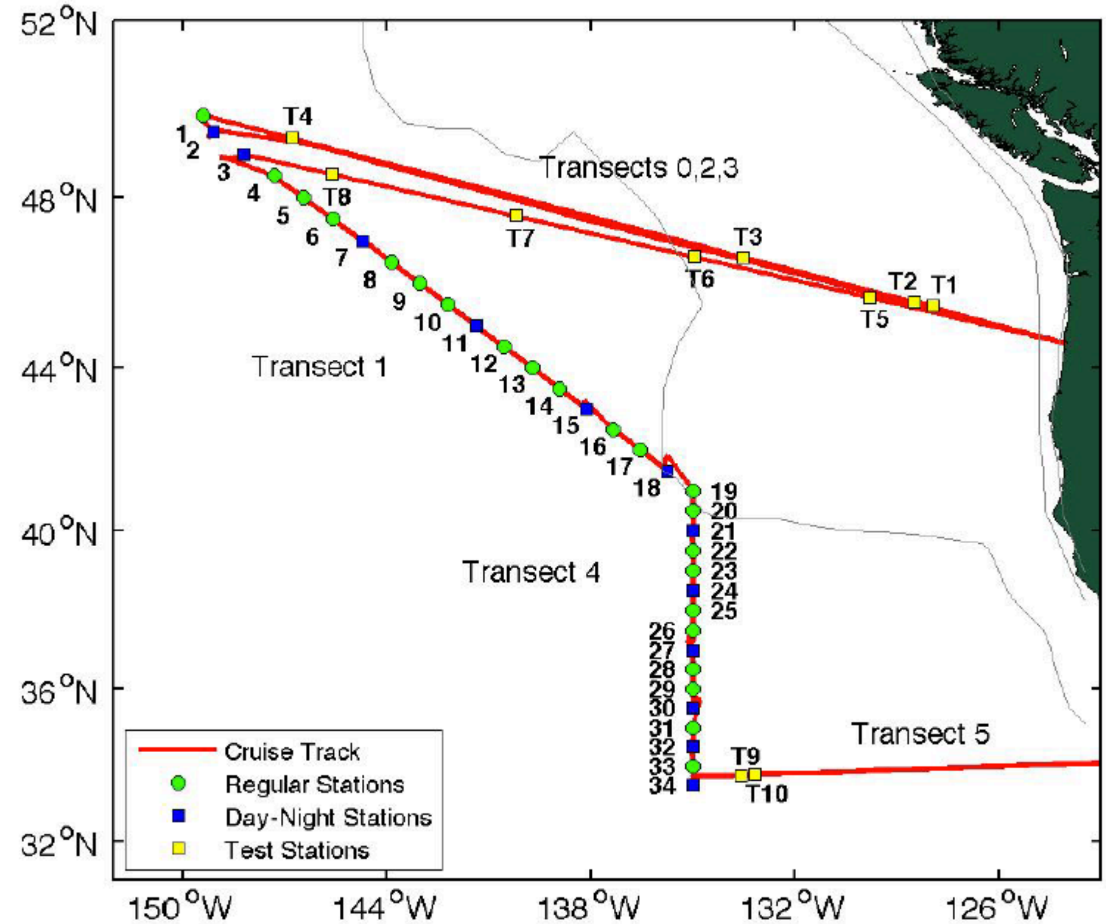
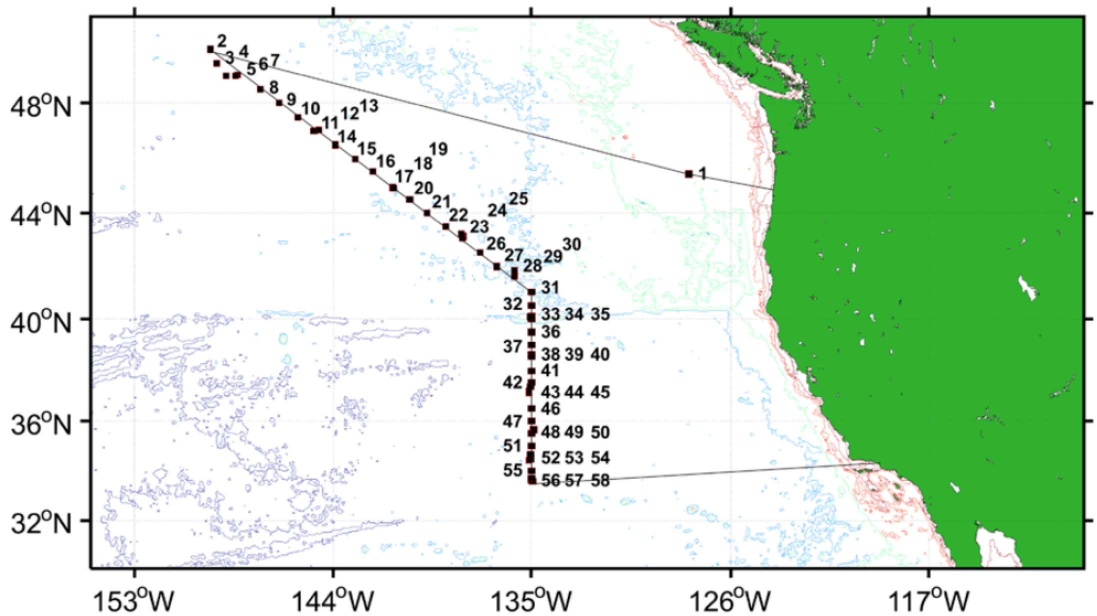

52°N
48°N
44°N
40°N
36°N
32°N
150°W
144°W
138°W
132°W
126°W
Transects 0,2,3
Transect 1
Transect 4
Transect 5
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
Cruise Track
Regular Stations
Day-Night Stations
Test Stations

**Figure 2.**



48°N
44°N
40°N
36°N
32°N
153°W
144°W
135°W
126°W
117°W
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33 34 35
36
37
38 39 40
41
42
43 44 45
46
47
48 49 50
51
52 53 54
55
56 57 58


**Figure 3.**

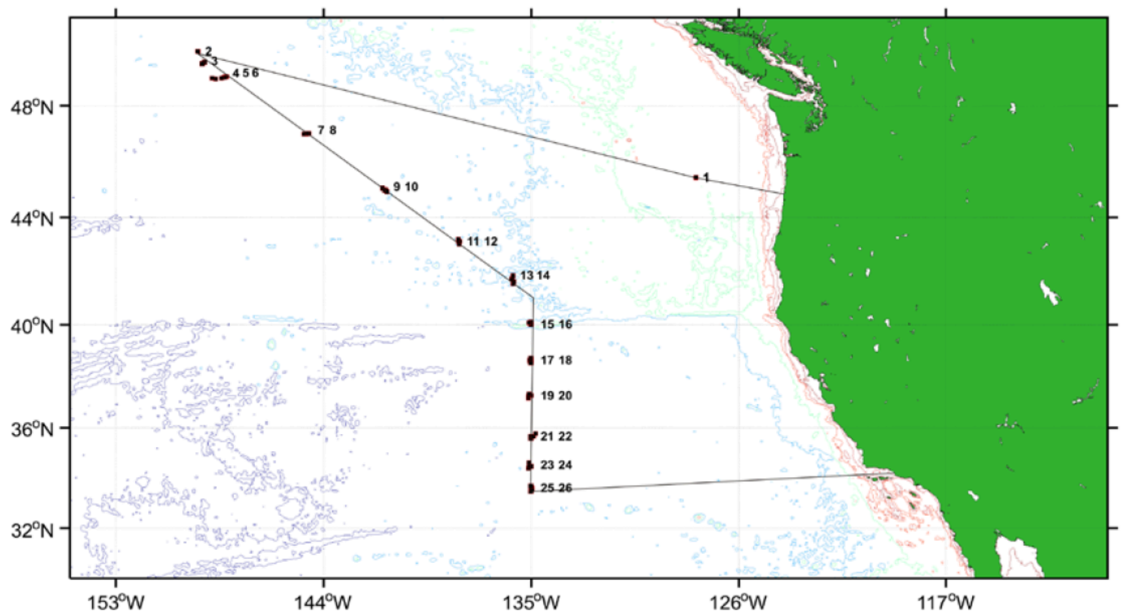

48°N
44°N
40°N
36°N
32°N
153°W
144°W
135°W
126°W
117°W
1
2
3
4 5 6
7 8
9 10
11 12
13 14
15 16
17 18
19 20
21 22
23 24
25 26

**Figure 4.**

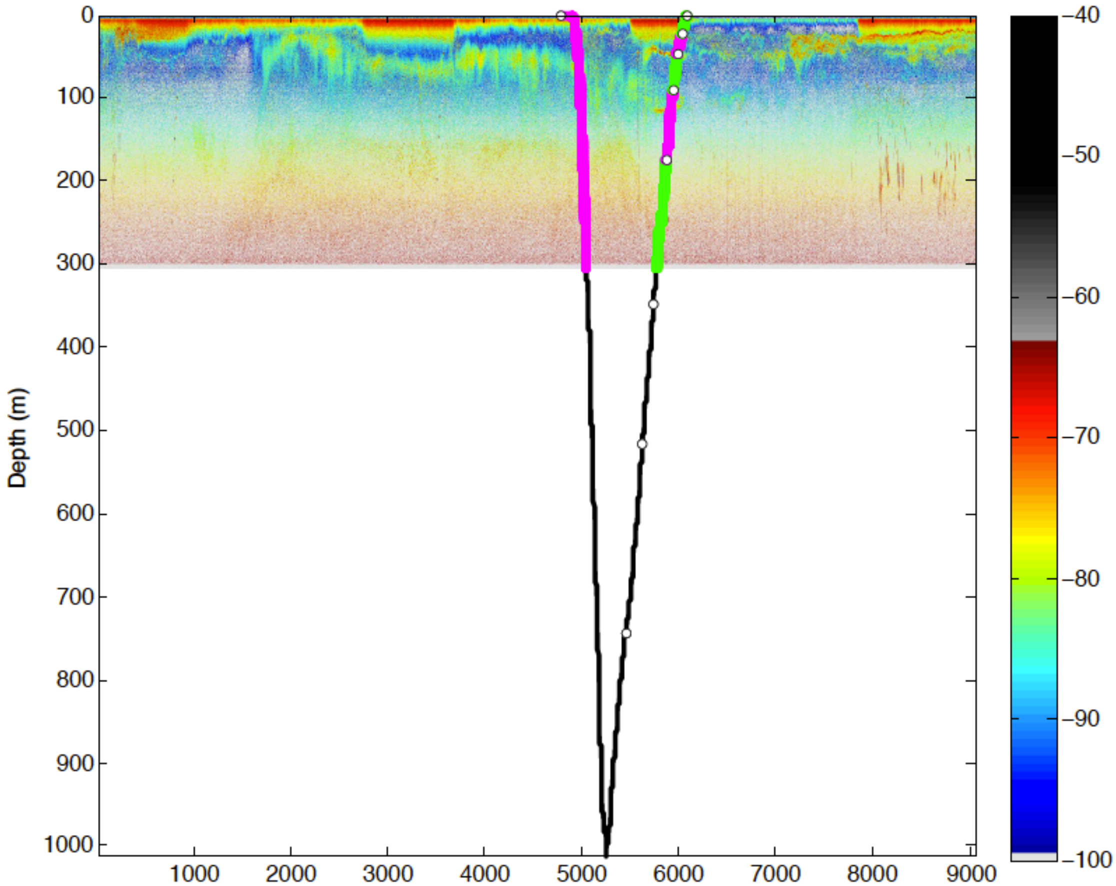

0
100
200
300
400
500
600
700
800
900
1000
Depth (m)
1000
2000
3000
4000
5000
6000
7000
8000
9000
-40
-50
-60
-70
-80
-90
-100

**Figure 5.**

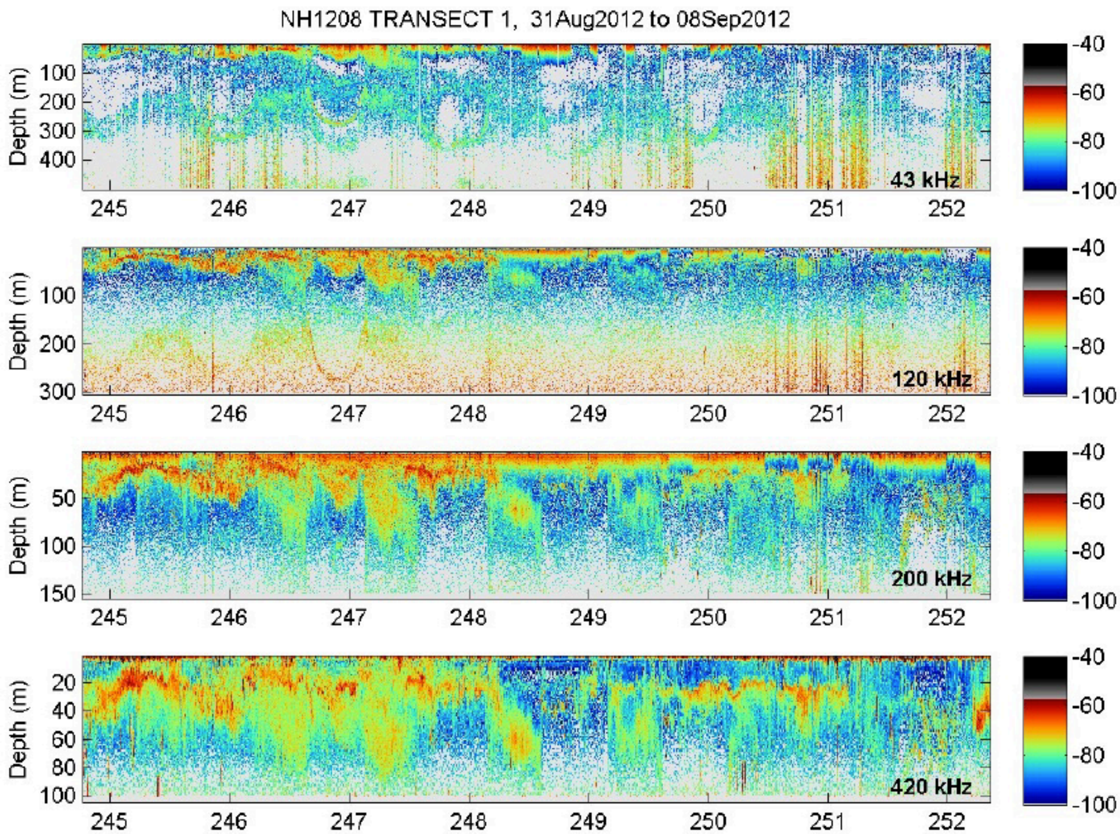

NH1208 TRANSECT 1, 31Aug2012 to 08Sep2012
Depth (m)
43 kHz
120 kHz
200 kHz
420 kHz
245
246
247
248
249
250
251
252
-40
-60
-80
-100

**Figure 6.**

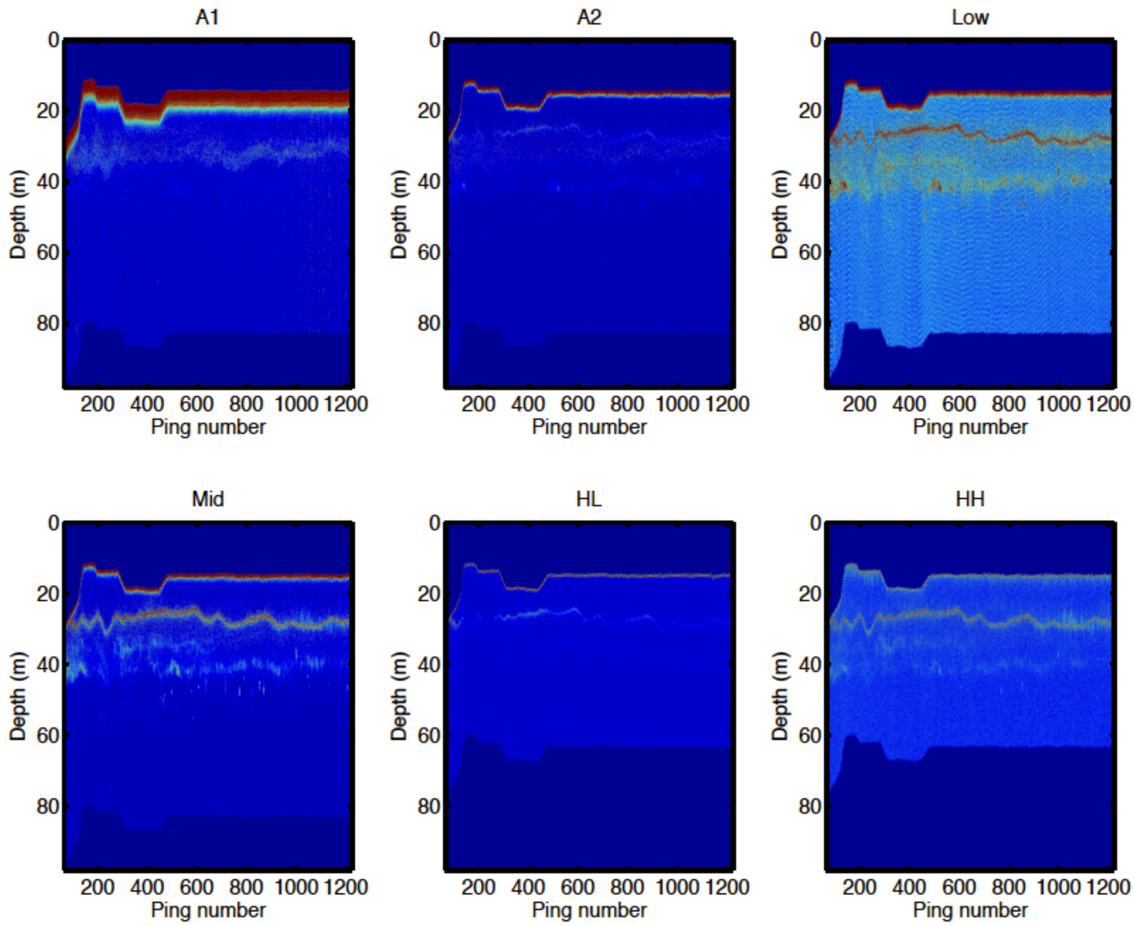

A1
A2
Low
Mid
HL
HH
Depth (m)
Ping number
0
20
40
60
80
200 400 600 800 1000 1200

**Figure 7.**

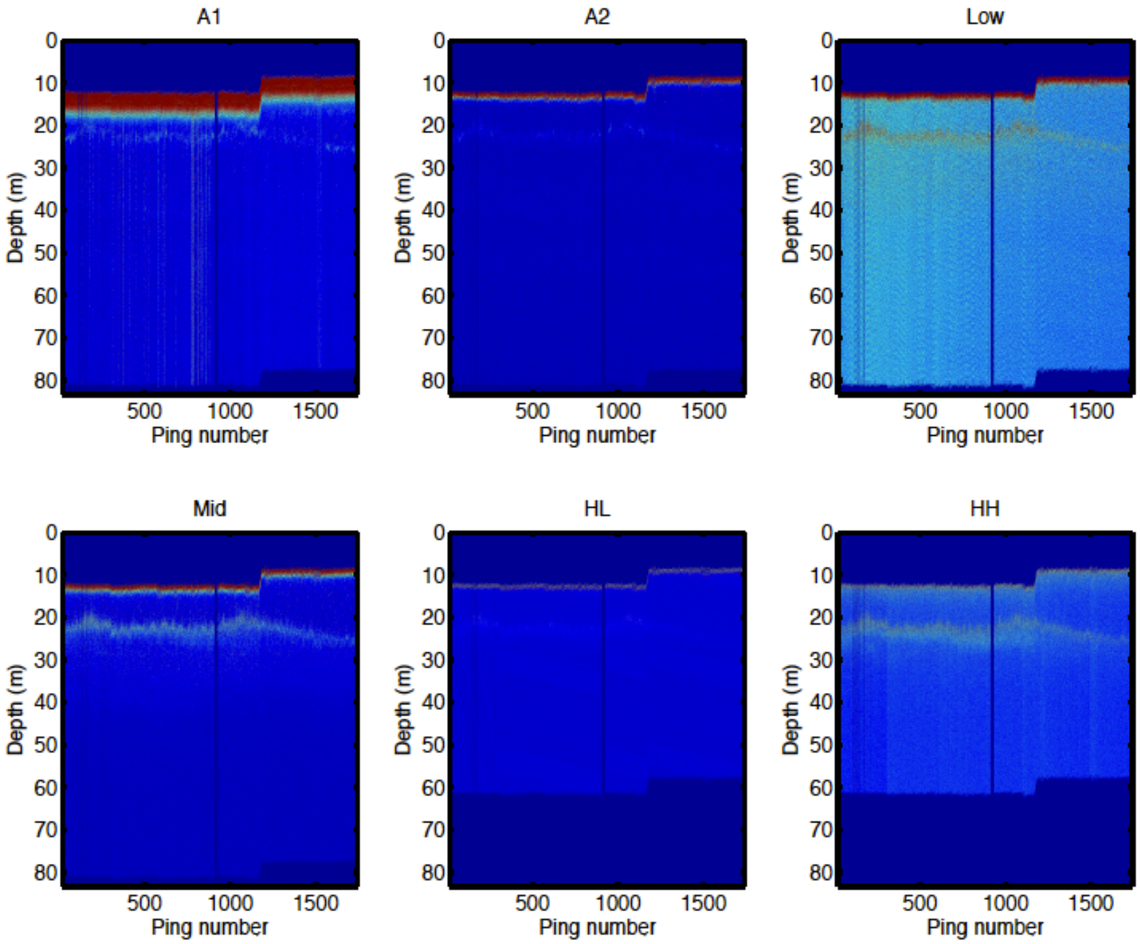
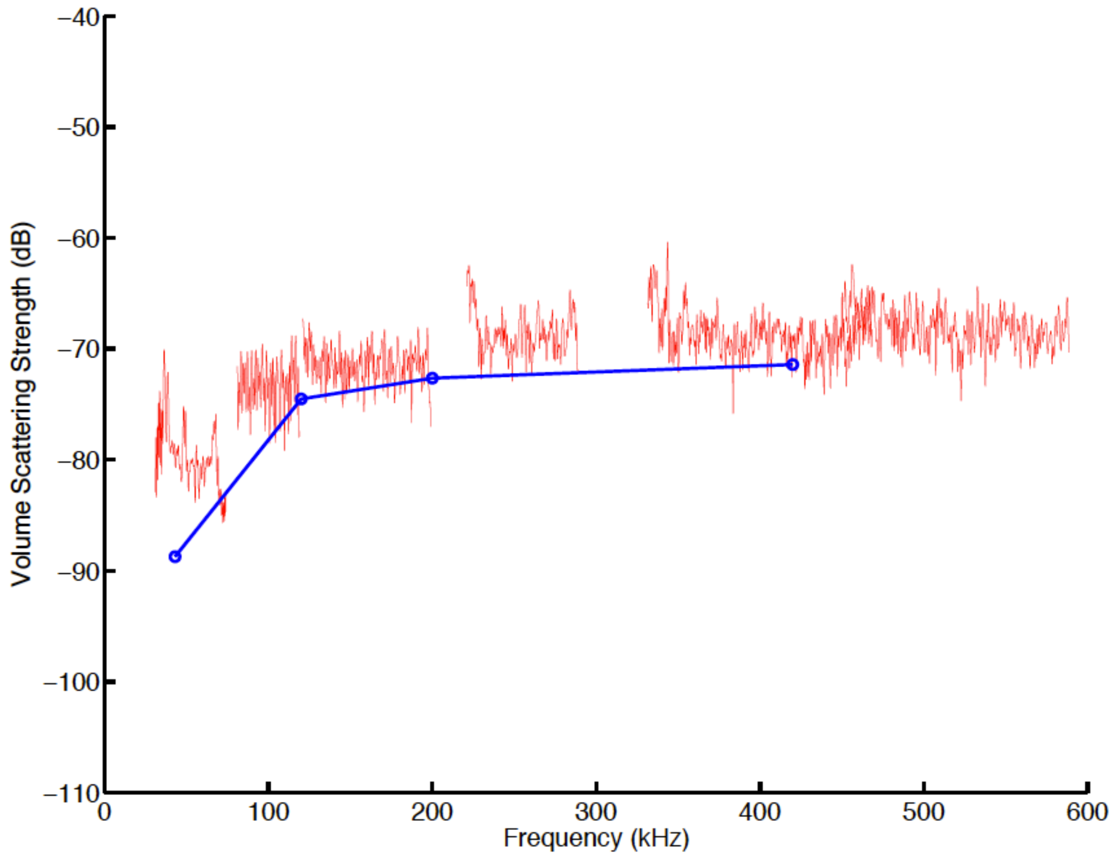
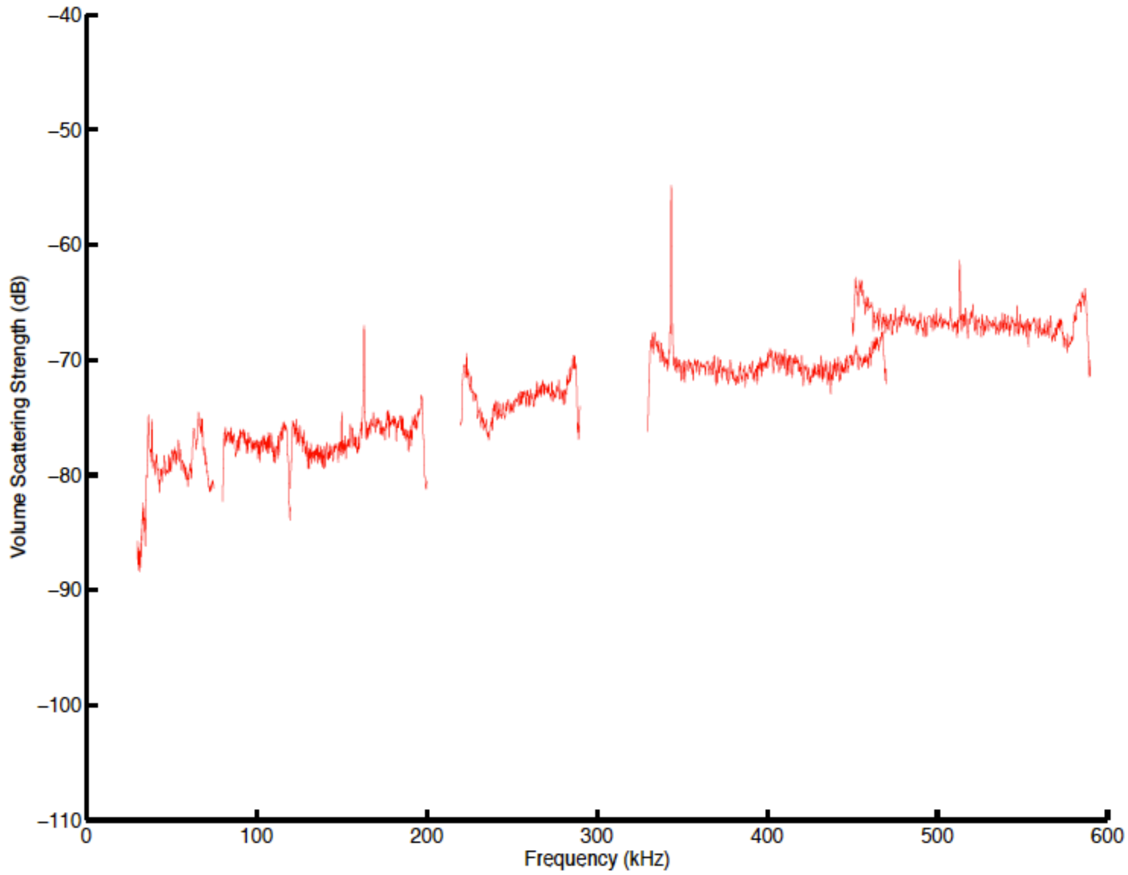

A1
A2
Low
Mid
HL
HH
Depth (m)
Ping number
0
10
20
30
40
50
60
70
80
500
1000
1500

**Figure 8.**



−40
−50
−60
−70
−80
−90
−100
−110
0
100
200
300
400
500
600
Volume Scattering Strength (dB)
Frequency (kHz)


**Figure 9.**



−40
−50
−60
−70
−80
−90
−100
−110
Volume Scattering Strength (dB)
0
100
200
300
400
500
600
Frequency (kHz)


**Figure 10.**

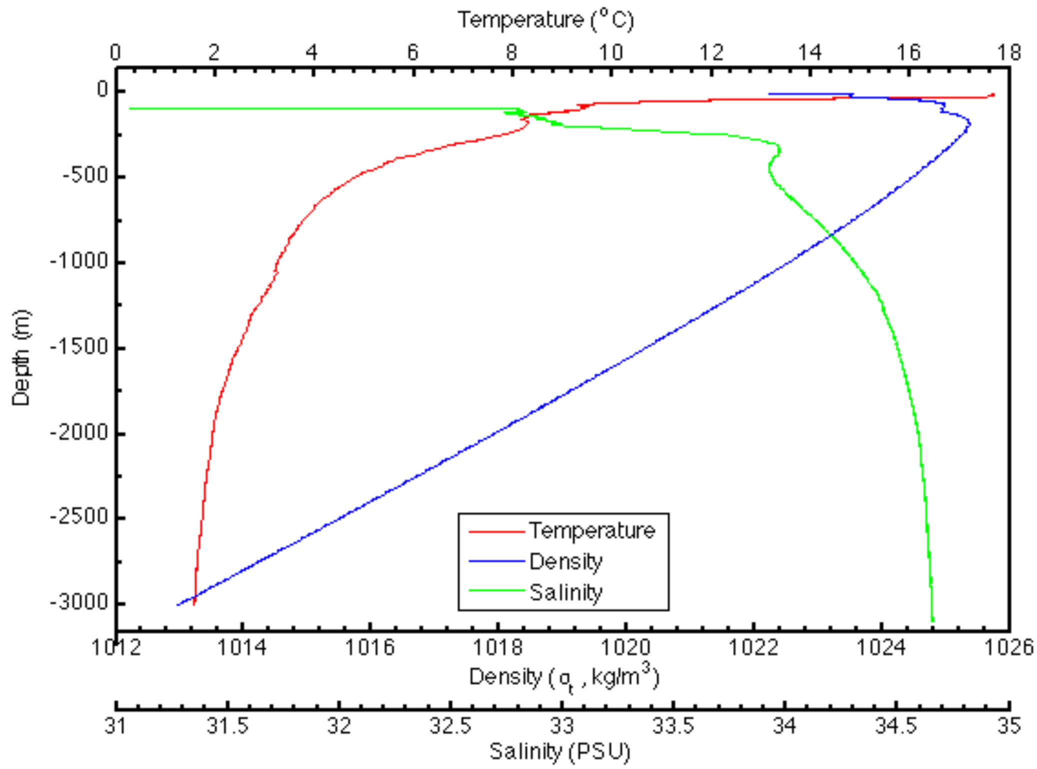
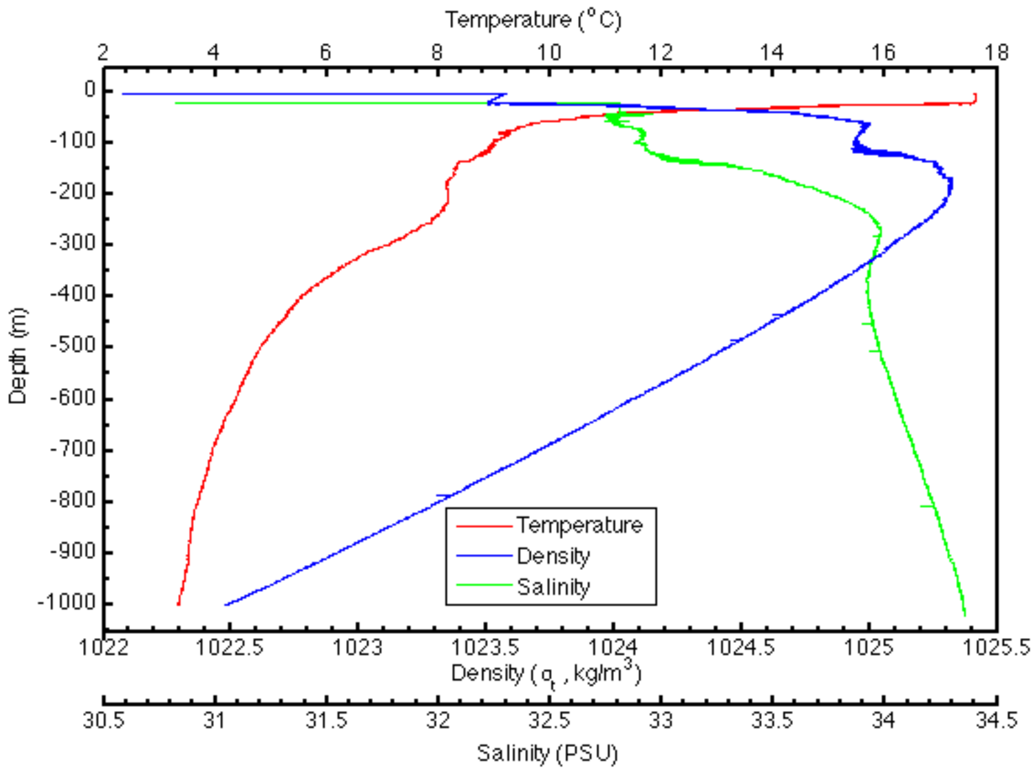
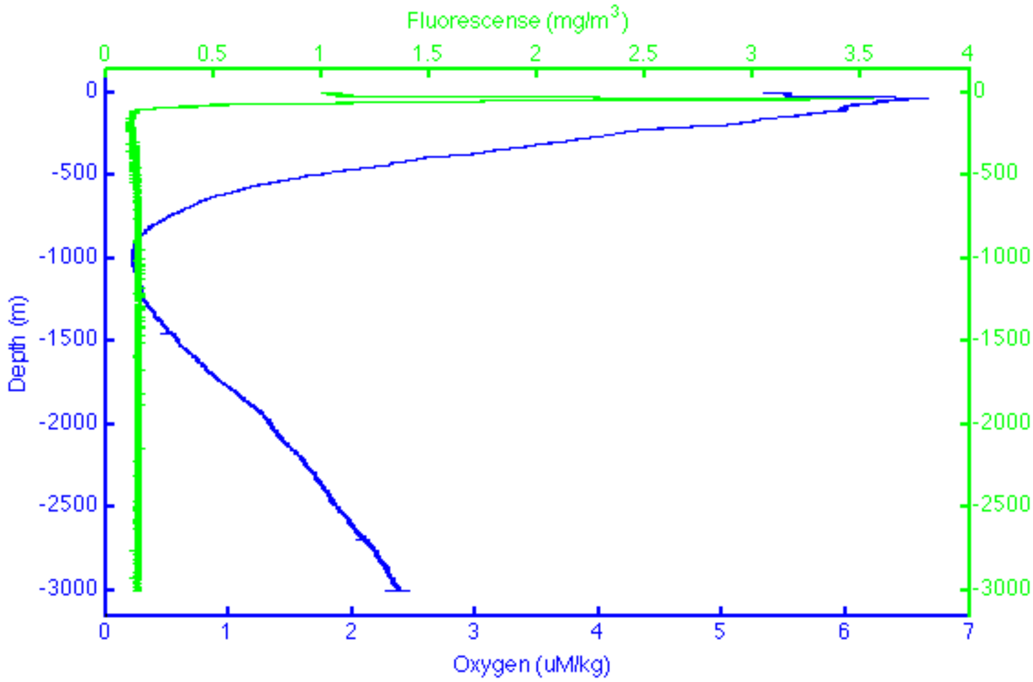

Temperature (°C)
0
2
4
6
8
10
12
14
16
18
0
-500
-1000
-1500
-2000
-2500
-3000
Depth (m)
Temperature
Density
Salinity
1012
1014
1016
1018
1020
1022
1024
1026
Density ($\sigma_t$, kg/m$^3$)
31
31.5
32
32.5
33
33.5
34
34.5
35
Salinity (PSU)

**Figure 11.**



Temperature (°C)
2
4
6
8
10
12
14
16
18
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
Depth (m)
Temperature
Density
Salinity
1022
1022.5
1023
1023.5
1024
1024.5
1025
1025.5
Density (σt , kg/m3)
30.5
31
31.5
32
32.5
33
33.5
34
34.5
Salinity (PSU)


**Figure 12.**



Fluorescense (mg/m3)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
-500
-1000
-1500
-2000
-2500
-3000
Depth (m)
0
1
2
3
4
5
6
7
Oxygen (uM/kg)


**Figure 13.**

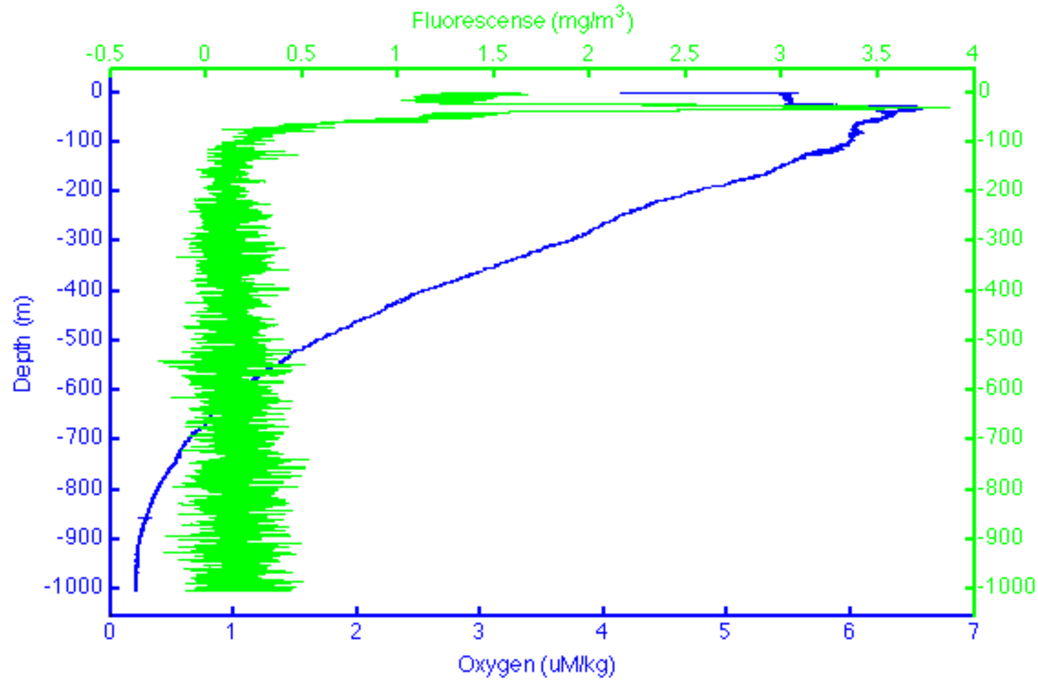

Fluorescense (mg/m3)
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
Depth (m)
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
0
1
2
3
4
5
6
7
Oxygen (uM/kg)

**Figure 14.**

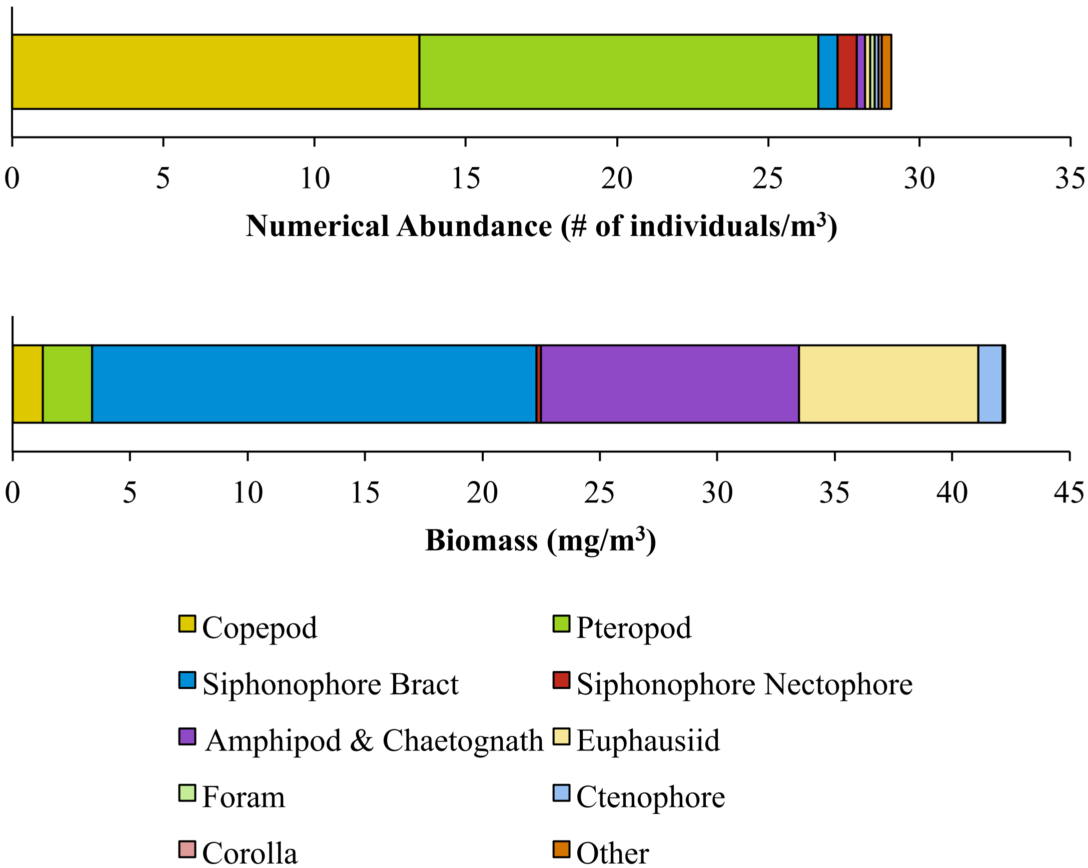
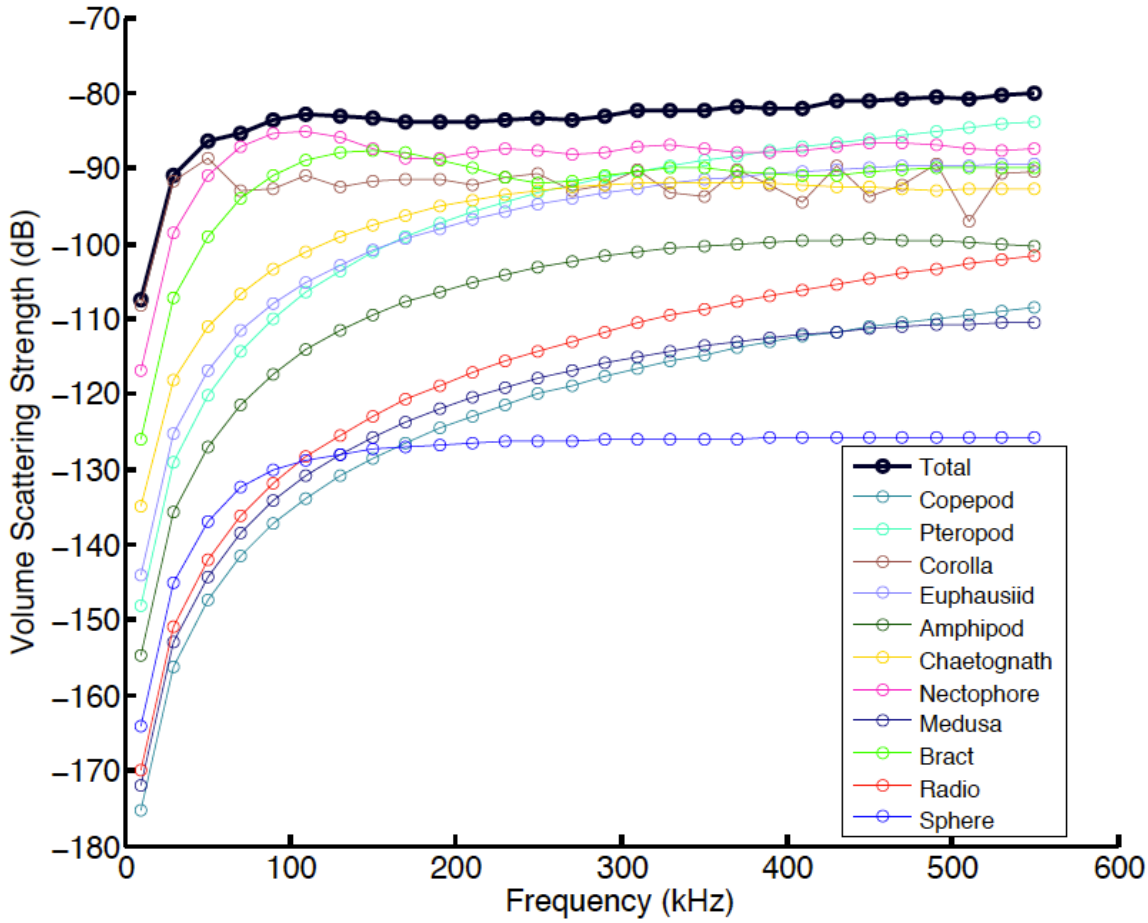

0
5
10
15
20
25
30
35
Numerical Abundance (# of individuals/m3)
0
5
10
15
20
25
30
35
40
45
Biomass (mg/m3)
Copepod
Pteropod
Siphonophore Bract
Siphonophore Nectophore
Amphipod & Chaetognath
Euphausiid
Foram
Ctenophore
Corolla
Other

**Figure 15.**



Volume Scattering Strength (dB)
Frequency (kHz)
−70
−80
−90
−100
−110
−120
−130
−140
−150
−160
−170
−180
0
100
200
300
400
500
600
Total
Copepod
Pteropod
Corolla
Euphausiid
Amphipod
Chaetognath
Nectophore
Medusa
Bract
Radio
Sphere


**Figure 16.**

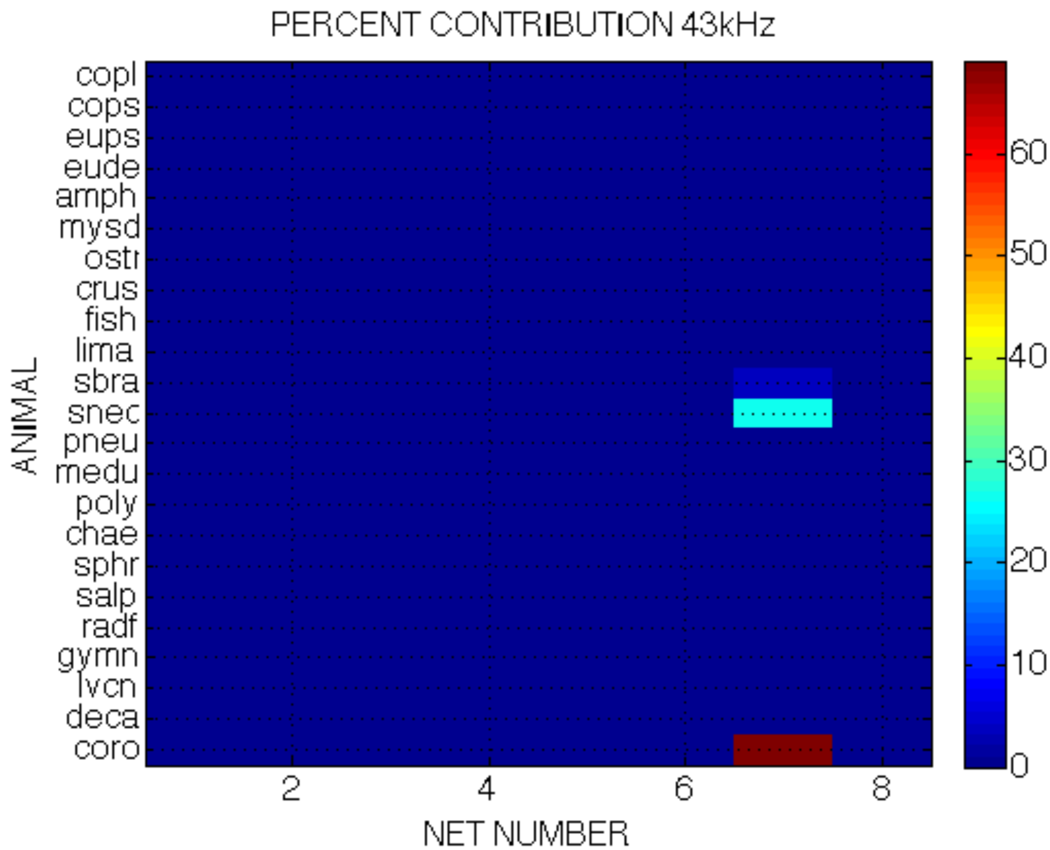
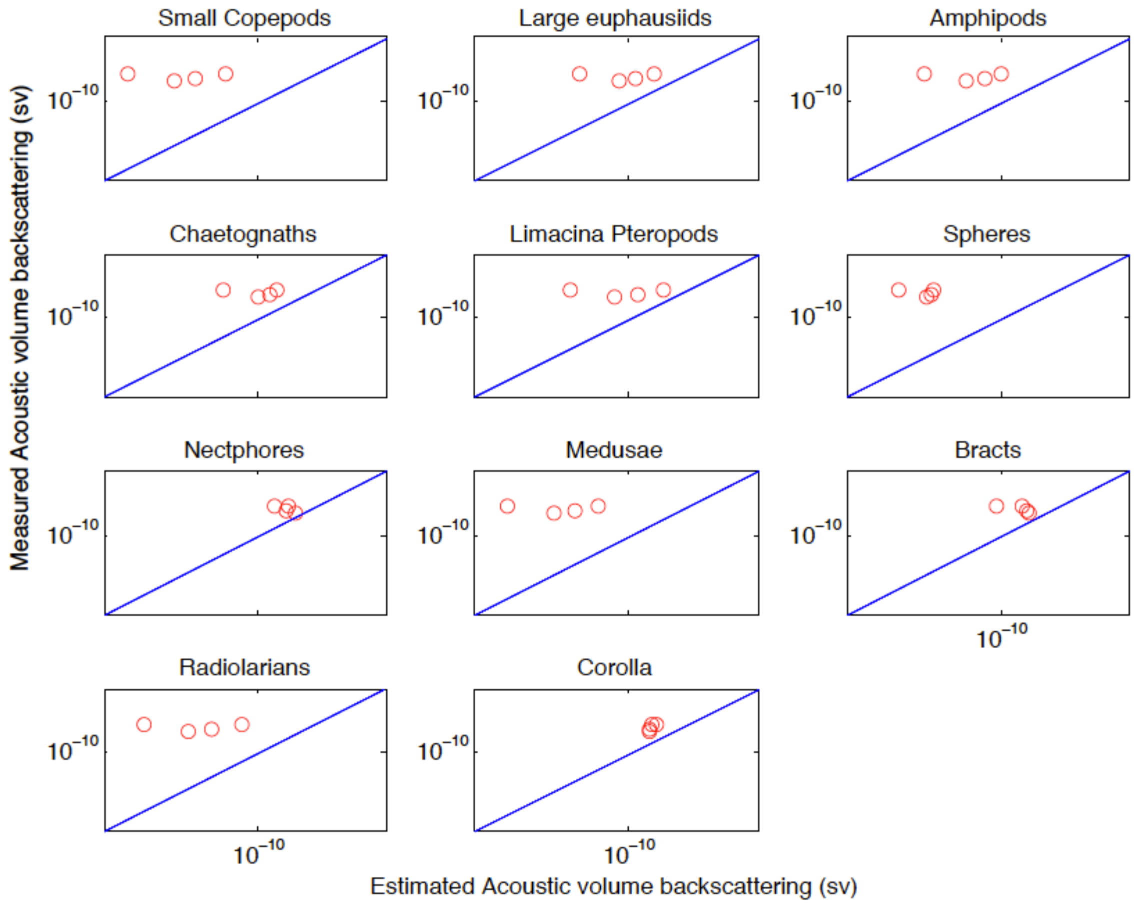

PERCENT CONTRIBUTION 43kHz
copl
cops
eups
eude
amph
mysd
ostr
crus
fish
lima
sbra
snec
pneu
medu
poly
chae
sphr
salp
radf
gymn
lvcn
deca
coro
ANIMAL
2
4
6
8
NET NUMBER
0
10
20
30
40
50
60

**Figure 17.**



Small Copepods
Large euphausiids
Amphipods
Chaetognaths
Limacina Pteropods
Spheres
Nectphores
Medusae
Bracts
Radiolarians
Corolla
$10^{-10}$
Measured Acoustic volume backscattering (sv)
Estimated Acoustic volume backscattering (sv)


**Figure 18.**

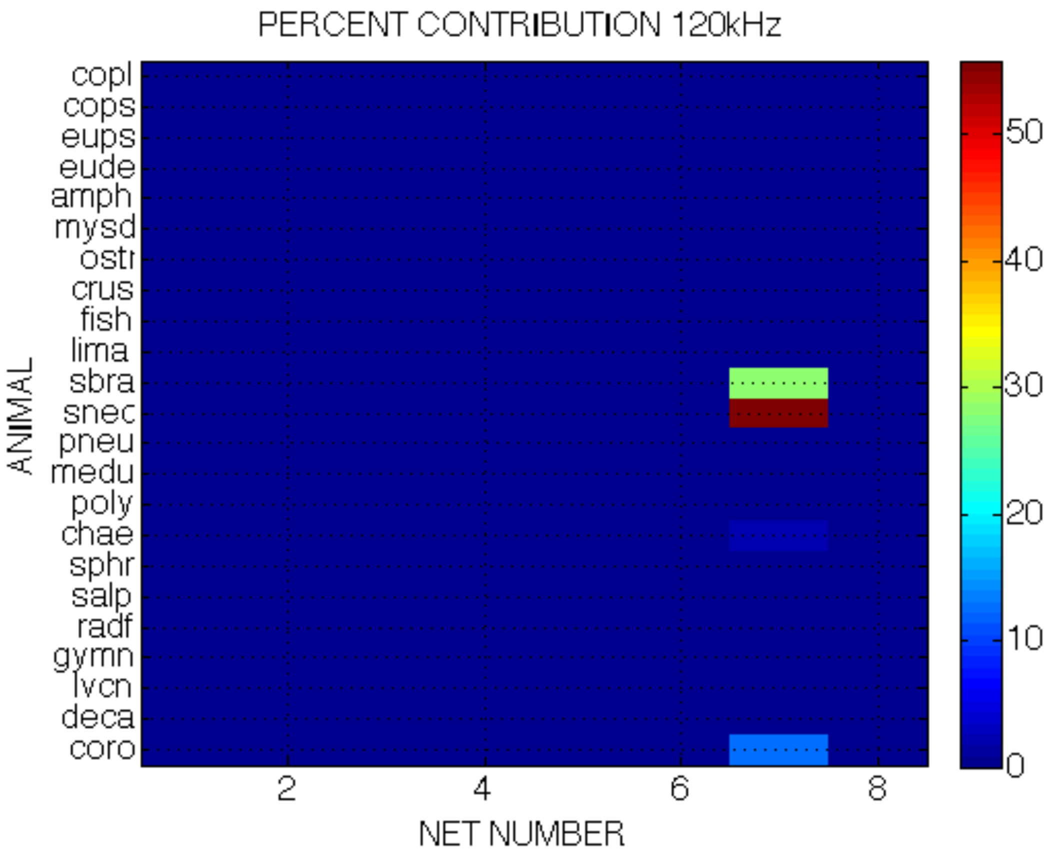

PERCENT CONTRIBUTION 120kHz
copl
cops
eups
eude
amph
mysd
ostr
crus
fish
lima
sbra
snec
pneu
medu
poly
chae
sphr
salp
radf
gymn
lvcn
deca
coro
ANIMAL
2
4
6
8
NET NUMBER
50
40
30
20
10
0

**Figure 19.**

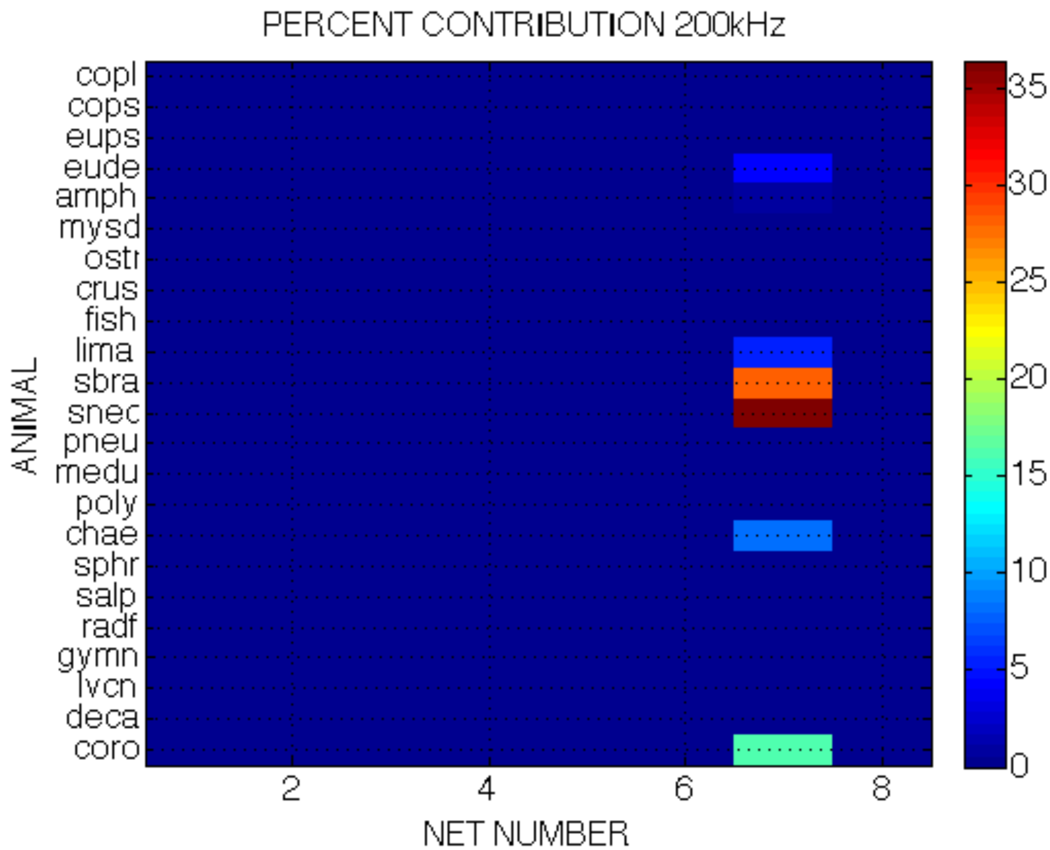

PERCENT CONTRIBUTION 200kHz
copl
cops
eups
eude
amph
mysd
ostr
crus
fish
lima
sbra
snec
pneu
medu
poly
chae
sphr
salp
radf
gymn
lvcn
deca
coro
ANIMAL
2
4
6
8
NET NUMBER
35
30
25
20
15
10
5
0

**Figure 20.**

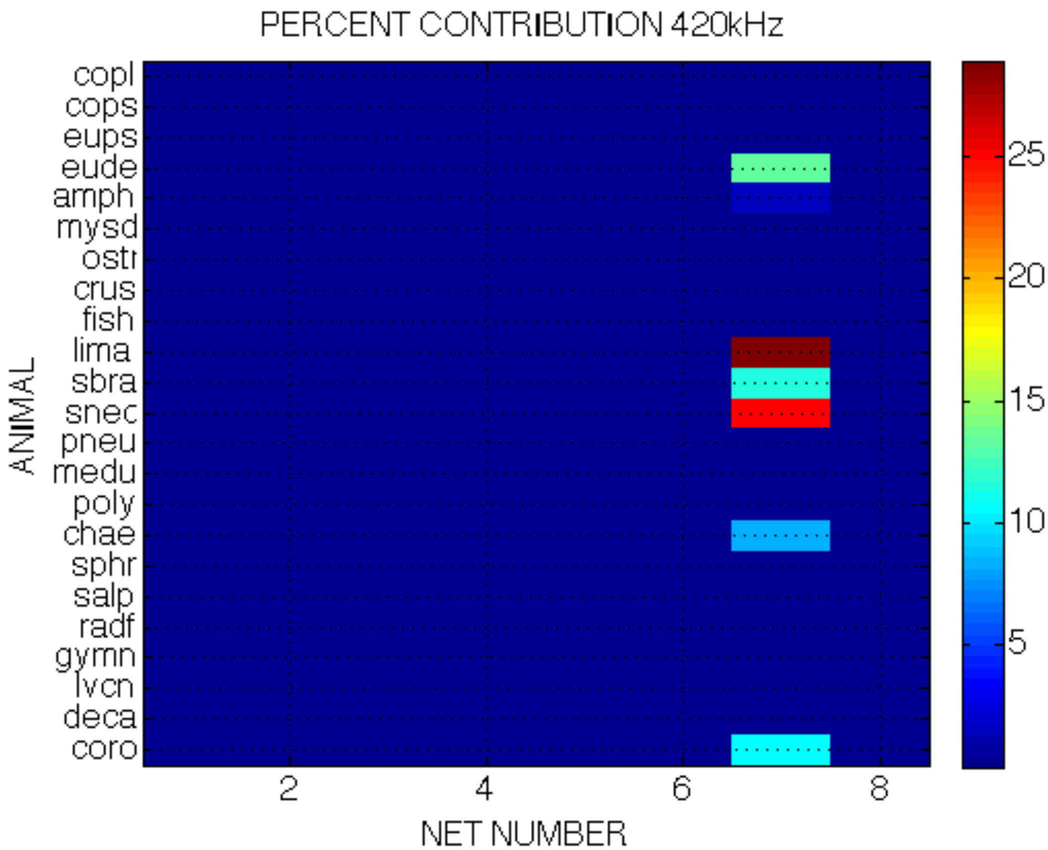

PERCENT CONTRIBUTION 420kHz
copl
cops
eups
eude
amph
mysd
ostr
crus
fish
lima
sbra
snec
pneu
medu
poly
chae
sphr
salp
radf
gymn
lvcn
deca
coro
ANIMAL
2
4
6
8
NET NUMBER
25
20
15
10
5

**Figure 21.**

# 4.0 Personal Objectives

## 4.1 Review of Personal Objectives

All my personal objectives were fulfilled during the work term. Each was realistic and appropriate. The discussion below focuses on how each objective was fulfilled.

### 4.1.1 Explore and experience the New England region

This work term provided a unique opportunity to live and work in a region of the United States that I had never explored. While in Woods Hole, Massachusetts, I had the opportunity to visit the Marine Biological Laboratory (MBL), Woods Hole Science Aquarium, and Sea Education Association campus, where I will be attending classes in the fall semester. I also had the opportunity to explore other cities in the region including New York City, New York, Providence, Rhode Island, Boston, Massachusetts, and Martha's Vineyard, Massachusetts. Even though most of the tourist destinations were far away from the institution, students who had brought vehicles generously offered to bring others along. I cannot believe all the incredible experiences that I had during this work term.

### 4.1.2 Acquire experience in a foreign country and in a private-sector research environment

As most of my previous experience has been in the academic-based research community in Canada, I did not know what to expect in a private-sector research environment, especially one in a foreign country. However, the academic research environment and the private-sector research environment are extremely similar. Yet, being an international student did provide a different outlook on the experience. More detailed observations of this workplace will be discussed in section 5.0.

### 4.1.3 Build relationships with supervisor, other scientists, students and members of the community

Networking has become a necessity to ensure future success and development of one's career. Working in harmony with others and contributing to group effectiveness are essential when building relationships with supervisors, other scientists, students and members of the community. During the work term, I joined the Tunes at Noon. Through my participation with the group, which played fiddle music every Tuesday at noon, I met numerous administrators at Woods Hole Oceanographic Institution and members of the Woods Hole community. Additionally, I had the opportunity to socialize with members of my laboratories outside of work hours. From them, I learned about graduate opportunities both at Woods Hole Oceanographic Institution and at other universities. They also generously assisted me in the comprehension of concepts and preparation of presentations.

### 4.1.4 Explore graduate opportunities at Woods Hole Oceanographic Institution

Woods Hole Oceanographic Institution has one of the premier marine science graduate programs. Patterned with Massachusetts Institute of Technology, the program offers Ph.D. programs in Applied Ocean Science and Engineering, Biological Oceanography, Chemical Oceanography, Marine Geology and Geophysics, and Physical Oceanography. Additionally, Woods Hole Oceanographic Institution offers various fellowships with other universities such as Duke University and Cornell University. The institution provides admission with full funding (i.e. stipend, health insurance and tuition).

I also had to opportunity to meet and discuss the programs at Woods Hole Oceanographic Institution with Dr. James Yoder, the Vice President for Academic Programs. I gained invaluable insight about the admission process and expectations. I am now much better prepared for the graduate admission process.

### 4.1.5 Participate in Woods Hole Oceanographic Institution events

During the work term, I had the opportunity to attend the Summer Lecture series, Biology, and Applied Ocean Physics and Engineering Department seminars and an Ethics in Science Workshop. The Summer Lecture series were held weekly and covered topics in biology, chemistry, geology, physics and engineering. Biology, and Applied Ocean Physics and Engineering Department seminars were also held weekly and covered topics ranging swimming by medusa to the spatial properties of ambient noise. The Ethics in Science Workshop was a mandatory workshop for all students participating in the fellowship program. Topics covered included plagiarism and authorship in scientific papers. I also had the opportunity to attend multiple public events, which included meeting James Cameron and viewing the Deep Sea Challenger.

### 4.1.6 Find a potential graduate school advisor

I have identified four potential graduate school advisors at Woods Hole Oceanographic Institution. These include my supervisors, Dr. Andone Lavery and Dr. Gareth Lawson, in addition to Dr. Mark Baumgartner, and Dr. Aran Mooney. The research of each of these scientists has a focus on acoustics, a field that I am interested in pursuing. Further discussion with each of them will be required in about a year, when I am entering my final year of undergraduate studies, to determine if there is a possible match.

## 4.2 Assessment of Personal Development and Performance

Living in a small town during the work term presented many challenges. Reaching services was the most challenging aspect due to a limited local transportation system. Additionally, I did not encounter challenges associated with living in a foreign country because the customs in the United States of America are not dissimilar from those in Canada. Further, the institution was well prepared for international students, which greatly eased the transition. This work term provided an opportunity for personal development. I was able to stay in contact with friends at home and to participate in activities outside the workplace. I also made some lifelong friends, which I will be visiting when I return to the fall semester. Overall, this was an incredible opportunity for personal growth and learning.

# 5.0 Observations of the Workplace

## 5.1 Relationships Within and Outside of the Workplace

I felt as though I "fit in" perfectly while on the work term. My supervisors provided the same amount of feedback, expected the same quality of work, and invited me to join the same seminars and symposiums as the students in their laboratory. I was always included in discussions and was able to contribute to the conversations. Both Dr. Andone Lavery and Dr. Gareth Lawson were extremely helpful and present throughout the work term. They created a great work environment, introducing myself to their graduate students, and encouraging me to seek advice and help from them. Both were available to answer any questions and to help with any difficulties I encountered. During the work term, Dr. Lavery and Dr. Lawson became great mentors, aiding me in further exploring opportunities at Woods Hole Oceanographic Institution. I also had the opportunity to build a relationship with each of them outside of the office. Their laboratories often gathered after work and even attended the county fair together.

An office was shared with Ph.D. candidate Erin LaBrecque. She was extremely helpful and incredibly supportive throughout the work term. At various seminars we attended together, Erin introduced me to other graduate students in the department. As a result, I was invited to social gatherings on numerous occasions. We also discussed topics ranging from fashion to science in the office. I also had the opportunity to interact with other members of the laboratories both within and outside of the workplace. I participated in the WHOI softball league, which provided me the opportunity to interact further with members of my laboratories and other scientists at the institution.

### 5.2 Comparison of Work Styles Between the Workplace and the Academic Setting

In the workplace, students are often asked to independently make important decisions. Supervisors may offer direction; however do not make final decisions. The amount of supervision provided varies depending on the needs of individual students and the stage of the project. Although success is achieved as individuals, supervisors are actively involved and often aid in the completion of small-scale projects. This increases the probability of success of the encompassing large-scale project and thus, the success of each individual student in their laboratories. Due to the large number of individuals generally involved in a project, communication between laboratory members is key. Reporting and recording work is important in many studies as they are not started and completed by the same students. Yet, email is the most important tool as it is often used to set meeting times and share thoughts about various aspects of the project. All students are given the opportunity to express his or her opinion. However, individuals working on the project are given the responsibility to decide the direction of the work. Taking the initiative to find innovative solutions is greatly encouraged. Problem-solving skills are essential for such solutions and lead projects to new directions.

In the academic environment, students are usually informed about decisions and expected to abide by them. It is also common to select one “correct” opinion to ease grading and to save time. Thus, differences of opinion are not always encouraged. Due to the large number of students in classes, students do not typically experience one-on-one supervision with the professor. It is the responsibility of the student to complete assignments on time and to attend classes. However, most projects are small-scale and the completion of one small-scale project generally does not affect the completion of others. Students often work as a team to complete projects. They exchange cell phone numbers, and communicate regularly through social media such as Facebook to set up meetings and to stay informed about the progress of projects. Yet, students are achieving more individualistic goals such as marks in the academic setting. Thus, initiative is emphasised as it often leads to greater success. Learning new problem-solving skills is emphasised, as they are needed when applying knowledge such as during laboratories, tests or exams.

### 5.3 Workplace Politics and Lines of Authority

Office politics mostly surrounded the issue of funding. In the private-sector research community, all projects undertaken and salary are dependent on funding. An extensive review process is implemented at the institution to ensure that scientists receive the maximum amount of funding possible. An on-going debate was about if the government was adequately funding ocean exploration. Additionally, peer-reviewed publications are used as a measure of success in this environment. During my work term, Dr. Gareth Lawson was promoted to Associate Scientist. It was regarded as a great achievement and was celebrated as it meant that he had met the extremely high publication standard of the institution.

### 5.4 Feedback, Criticism, Self-Confidence and Assertiveness

During the work term, constructive and positive feedback was regularly provided to all students by the supervisors. This was meant to encourage individuals to improve existing ideas or develop new ones. Responses to suggestions and criticisms were generally positive. I frequently sought feedback from my supervisors to improve my performance in the workplace. I attempted to always respond promptly and positively.

Self-confidence and assertiveness were not only valued, but encouraged in the workplace. The frequent positive feedback received helped increase the self-confidence of many students, including myself. In turn, this improved the overall quality of the work produced. In the workplace, assertiveness is required not merely to have a good idea, but to develop it, fight for it, win supporters for it and do everything within one's power to see that it get translated into reality. Assertiveness was often recognised by the supervisors.

## 5.5 Time and Stress Management

By managing my time more wisely, I was able to minimize stress. Prioritising, organizing and not over-committing helped develop a balanced schedule, which included breaks and social activities. This was done using to-do lists. Additionally, minimizing distractions, avoiding procrastination and resisting perfectionism saved copious amounts of time, and improved the overall quality of my work. These techniques greatly reduced stress, and improved my physical and emotional well being.

# 6.0 Work Term Conclusions and Recommendations

## 6.1 Expectations of the Work Term

The work term far exceeded all of my expectations. I did not expect to have a complete and comprehensive project by the end of the work term. I am currently working on a publication with Dr. Andone Lavery and Dr. Gareth Lawson based on this work. My supervisors were extremely helpful and present throughout the work term. The amount of support and advice that I received from both of them and their students was overwhelming. I accomplished much more than both my supervisors and I expected.

## 6.2 Difficulty Level of the Work Term

Based on my skills and previous experience, the work term was of an appropriate level. During the work term, I was challenged to use my previous knowledge of concepts related to physics (e.g. Fourier transforms) to not only analyze, but also understand and present acoustic data. However, without previous programming skills, this work term would have been too difficult for any undergraduate student. Many of the objectives were dependent on this skill set.

## 6.3 Enjoyment of the Work Term

I extremely enjoyed this work term. Since the material was both interesting and challenging, I remained engaged throughout the work term. I sincerely hope to have the opportunity to work with Dr. Andone Lavery, Dr. Gareth Lawson and the members of their laboratories in the future. I would be overjoyed to continue working on this study in my final work term and to work with either of my supervisors as a graduate student.

## 6.4 Recommendations for other Co-op Students

Science co-op students interested in a similar work term should have previous experience in programming, particularly in MATLAB®, and strong mathematical skills. Programming and mathematical skills were vital to the completion of many of the duties outlined and expected during the work term. For students with this previous knowledge, I would absolutely recommend the position. It was an invaluable learning experience. This position would be an appropriate third or fourth work term in a student's co-op degree.

## 6.5 Working in a Similar Environment on a Permanent Basis

Working on a permanent basis in the private-sector research community would be highly desirable. It is an environment that I find suits my personality. The setting values initiative, organization and creativity in individuals. Additionally, there is considerable flexibility in terms of both subject investigated and when hours are worked. Further, acoustics is a field that I greatly wish to further investigate in the future. However, topics focused more on the effects of anthropogenic noise on marine mammals would be desired research areas.

## 6.6 Conclusions on the Academic Aspects of the Work Term

During the work term, I gained additional experience in research, and skills that will greatly help secure my final work term and graduate positions. This research experience may lead to my third publication, which will further help increase my ability to successfully enter graduate school. I also had the opportunity to explore a new workplace environment and conduct research in a field that I have always been interested in, acoustics. Additionally, I have found amazing mentors in Dr. Andone Lavery and Dr. Gareth Lawson. The academic aspects of the work term exceeded my expectations.

### 6.7 Conclusions on the Personal Aspects of the Work Term

I was extremely pleased that I had the opportunity to fulfil my personal objectives throughout the work term. Accomplishing each personal objective has given me a greater sense of confidence that I will be able to succeed both professionally and personally in this type of workplace environment, as it is the type of setting that I wish to work in on a permanent basis in the future. In addition, I am extremely pleased that I used what I learned during my work term at Memorial University of Newfoundland to easy my transition when I arrived at Woods Hole Oceanographic Institution. Overall, this was the best work term to date.

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