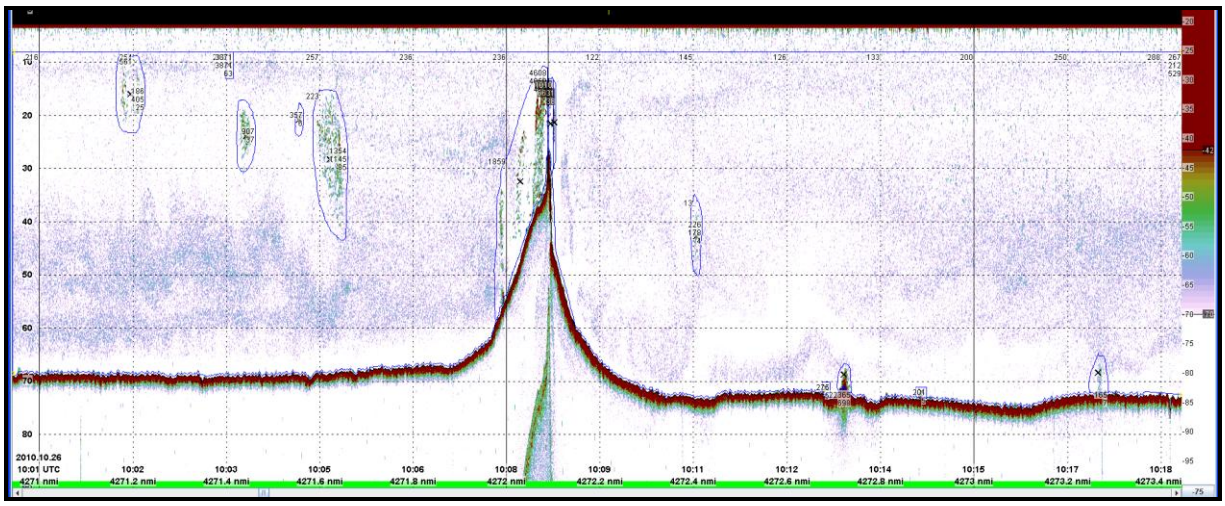
Zooplankton abundance and distribution around on a seamount in the Andaman Sea, Thailand, measured with acoustic methods and biological sampling



By

Issarapon Jithlang

A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Science
In
Fisheries Biology and Management

University of Bergen, Norway
Department of Biology
2011

Echogram from the acoustic survey in the October 2010.

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Abstract

Studies of abundance and distribution of zooplankton with acoustic instruments is new methodology in Thailand. In order to evaluate if the zooplankton could be detected and measured, a specific area around a seamount in the Andaman Sea was selected for comparative measurements zooplankton with acoustics and with biological sampling. The survey was conducted with the Andaman Sea Fisheries Research and Development Center vessel RV "Pramong 4" in 3 cruises during the southwest monsoon period from 14^{th}-17^{th} of August, 14^{th}-17^{th} of September and 26^{th}-30^{th} October 2010 working both during day and night. The survey area covered the Hin Muang–Hin Daeng seamount located on southeast part of Krabi province between 07^{o} 08.98′ N and 98^{o} 49.41′ E. The acoustic surveys used SIMRAD EK60 echo sounder with split beam transceivers at 38 and 200 kHz. The acoustic data were collected on four transects crossing the seamount in a "star" pattern. The distance of each transect is 6 nautical miles.

The biological data was collected at 2 sampling sites placed on transect line 3 of acoustic sampling: Site 1 was relatively near to the seamount, at 0.5 nautical miles distance, and Site 2 far from the seamount at 1.5 nautical miles distance. Two sampling gears were used to study the abundance and distribution of zooplankton. The Bongo net with 330 μm mesh size equipped with a flow meter and depth sensor was the main gear for studying of mesozooplankton and fish larvae. The Van Dorn 20 liters water sampler was applied for studying of microzooplankton. Both gears were used to take several samples in the vertical.

Salinity, temperature, dissolved oxygen, pH, sea current speed and direction were recorded at both sites, using a CTD and a current meter.

The results showed that the environmental parameters; dissolved oxygen (2.49-4.49 mg/l), temperature (28-30^{o}C), salinity (32.00-33.43 psu) and pH value (8.28-8.52) around the seamount was quite stable throughout the sampling period. The ocean current during the period flowed cyclically in an east western direction.

The density of plankton-like targets around seamount evidently varied around the pinnacle area, the horizontal distribution in September and October showed similar pattern at all transect lines with a sharp decreased density at pinnacle area at both frequencies. The same pattern was seen in some of the August transects. The acoustically measured abundance of zooplankton (copepods) at the area outside the pinnacle area was higher than at the pinnacle area throughout study period with mean abundance 54.50±19.60 kg/m^2 and 44.23±22.02 kg/m^2, respectively. From these high numbers, and from the comparative biological studies,

the echoes scrutinized as zooplankton could not have been zooplankton, and the main smoke-like targets and layers must have been gas bearing phytoplankton rather than echoes from zooplankton.

Almost all (98%) of the fish was found closer than 0.1 nautical miles from the pinnacle of the seamount. The biomass of fish was estimated to be approximately 18±9.90 tons. The abundance of zooplankton from the Bongo nets showed no difference between Sampling Site 1 (46-471 individuals/m^3) and Site 2 (40-564 individuals/m^3) Also, there was no significant difference between day and night sampling. The zooplankton dry weight biomass from the Bongo net collection ranged from 0.0020-0.0184 mg/m^3 at Sampling Site 1 and 0.0021-0.0170 mg/m^3 at Site 2. Additionally, the abundance of microzooplankton, studied with the Van Dorn sampling gear indicated no difference between Sampling Site 1 (550-6100 individuals/m^3) and Site 2 (1000-6900 individuals/m^3) during day and night. Copepoda were the most abundant taxon accounting for 70-79% of total zooplankton densities all both gears and both sampling sites. The main reason for the difference in the numerical abundances observed with the two sampling gears is animal size. The results from the zooplankton abundance investigations showed low correlation between acoustic measurements and biological sampling. The result indicates that there are significant errors involved, problems and limitations in the acoustic detection of the main zooplankton groups, but also with the two biological sampling devices.

However, the results also indicate that the zooplankton densities are very low in the study area of the Andaman Sea. Using only the 38 kHz and 200 kHz echo sounder frequencies made it therefore difficult to distinguish zooplankton on the echograms and to separate them from other masking targets.

Symbols and Definitions

σ	Acoustic cross section [m^2]
σ_{bs}	Backscattering cross section [m^2]
σ_{sp}	Spherical scattering cross section [m^2], = $4\pi\sigma_{bs}$
$<\sigma_{sp}>$	Average spherical scattering cross section [m^2]
TS	Target strength of one scatterer [dB re 1 m^2]
S_v	Volume backscattering strength [dB re 1 m^{-1}]
s_v	Volume backscattering coefficient [m^{-1}]
s_A	Nautical area scattering coefficient [m^2/nmi^2]
$<s_A>$	Average nautical area scattering coefficient [m^2/nmi^2]
s_a	Area scattering coefficient [m^2/m^2]
ρ_A	Area density [$\#/m^2$],[$\#/nmi^2$],
ρ_V	Volume density [$\#/m^3$]
g	Density contrast between the animal and surrounding sea water
h	Sound velocity contrast between the flesh and the surrounding sea water
A_0	An elementary area of the region being surveyed [nmi^2]
ESR	Equivalent spherical radius which is the radius of a sphere that contain the same volume as the scatterer displaces
CMCL	Cube root mean cubic length [mm]
DWBA	Distorted-Wave Born Approximation
N	Number of the zooplankton individual
V_B	Volume of water passed through the plankton net of Bongo [m^3]
V_V	Volume of water collected by Van Dorn sampler [liters]
n	Revolution number recorded by the flow meter
a	Surface area of the net opening [m^2]
M	Constant of displacement [m] per 1 revolution

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1. Introduction

Zooplankton is an important part of the food web of most marine ecosystems. The species composition, density and distribution of zooplankton have therefore direct relevance to fishery resources assessment. The production of zooplankton usually supports the higher trophic levels in marine ecosystem and may affect recruitment, fish production, growth rates and survival. These functions can be influenced by several factors, but a critical one the abundance of available zooplankton, since it serves as an important food source for juvenile and pelagic fish (Dettmers et al., 2003; Macfarlane et al., 2005; Schaus et al., 2002; Ware and Thomson, 2005)

Acoustic echo sounders have been used for detection and classification of marine organism for long time(Clay and Medwin, 1977). As a result of the ability of sound to be transmitted over great range in the ocean, the backscattering of several organism can be used in conjunction by nets or pumps, as a speedy survey methodology (Stanton et al., 1994). Acoustic investigations of density and distribution of zooplankton has been acknowledged in recent years. Holliday, Pieper and others described proper acoustic methods for zooplankton after initial improvement and utilization of acoustic methodology in fisheries research about two decades. Zooplankton investigations using acoustics is in many ways based on fisheries acoustics and fisheries research. Acoustic methods are often applied in order to supply swift vertical and horizontal distribution of zooplankton with an echo sounder, but the method must also be accompanied with biological plankton net and pump sampling (Foote and Stanton, 2000). In addition, zooplankton abundance estimation is usually followed by counting subsamples from the zooplankton gross sample collected by nets and pump (Greenlaw, 1979). The first, proper research paper on zooplankton acoustic was distributed in 1977 by Holliday (Holliday, 1977) and after this, zooplankton acoustics has matured to multi-frequency acoustic systems. The echoes from zooplankton are weak compared to echoes from fish, and usually it is the echoes from multiple targets (many individuals in the pulse resolution volume) that are visible on the echograms, but clearly above the background noise level. Echoes of single zooplankton targets are very weak, and seldom resolved into single target echoes, which could be used to infer animal size (Simmonds and Maclennan, 2005). Since the echoes of small, fluid like targets are strongly frequency-dependent, the use of data from multiple frequencies can be used to infer animal size from the echo response. Physics-based acoustic scattering models and mathematical inversion technique can be used to split the data into size distributions of the biological sound scatterers. Further studies on improvement of

the acoustic scattering models and assessment of zooplankton acoustics can be found in (Greenlaw, 1977; Greenlaw and Johnson, 1982; Holliday and Pieper, 1995).

Iida et al. (1996) explained how acoustic sampling in the ocean is a useful technique for studying the density and structure of distribution of several marine organism simultaneously. The method utilizes the acoustic backscattering characteristics for estimating biomass and distribution of zooplankton at a specific sampling site, or on survey transects. Simmonds and MacLennan (2005) described that plankton produce echoes with the same scattering laws as any other targets, but as that they are mainly small to microscopic objects close to another, echoes generally overlap to create cloud-like, but quite strong marks in echograms. We are therefore in the typical multiple target situations, where more than one target is generating the echo from the acoustic resolution volume. Since zooplankton is usually much shorter than the acoustic wavelength, their backscattering are in the socalled Rayleigh region,where the backscattering is exponentially increasing with acoustic frequency. The smaller they are the weaker is the echo at the conventional fisheries frequency 38 kHz and the stronger are their so-called frequency response (Korneliussen and Ona, 2002). Using several discrete frequencies simultaneously has therefore improved our ability to separate fish echoes from zooplankton targets. In addition, Foote and Stanton (2000) interpreted the main difference between fish and zooplankton acoustics to be that fish usually could be classified by the presence or absence of a swimbladder and their size variation while acoustic scattering from aggregations of zooplankton is characterized by containing several species and sizes with different acoustic properties. The evolution of standardized zooplankton acoustic method was first the development of, multiquency echosounder with similar and simultaneous transmission (Korneliussen et al., 2008). The inversion methods maybe used to deduce significant biological parameters from multiquency data by comparing the recorded data with physical-based scattering (Holliday et al., 1989). Investigation on zooplankton populations with acoustic methods are much more complicated than for populations of fish, mainly due to the weak backscattering of each animal but also due to the complexity of the plankton community (Stanton et al., 1994). The animal aggregation density must of course also be high enough to produce an echo well above the echo sounder background noise level, or above the level of unwanted, similar targets, like echoes from air filled phytoplankton.

Moreover, zooplankton acoustic surveys may cover a large volume of water, and are more rapid than net sampling (Flagg and Smith, 1989), and special structures in the plankton community, like layers or aggregating may be better described than by net sampling.

Most investigations in zooplankton acoustic includes calibrated and digitized data from multi-frequency echo sounder for separating and extracting the acoustic scattering from zooplankton and fish in mixed recordings (Korneliussen and Ona, 2002). The distribution of zooplankton along the South African coast by multifrequency acoustics and their relationships with physical parameters and anchovy distribution was presented by Lebourges-Dhaussy et al. (2009). Holliday et al. (1989) used multiple coustic frequencies for assessment to size and distribution of small zooplankton. Acoustic estimation of size distribution and abundance of larger zooplankton (euphausiids) was studied by Kristensen and Dalen (1986). Moreover, discrimination of backscattering strength at 38,120 and 200 kHz could be used to separate echoes originating from each of the dominant scattering layers and other signals from zooplankton in the Altantic sector of southern Ocean (Brierley et al., 1998). McKelvey and Wilson (2006) also used 38 and 120 kHz data to discriminate between fish and zooplankton on the Pacific hake survey off the west coast of the United States and Canada. Concurrently, Madureira et al. (1993a) used 38 and 120 kHz data to distinguish or discriminate between Antarctic krill *(Euphausia superba*) and other scatterers. Furthermore, they used the backscattering strength at 120 and 38 kHz to separate between three species of Antarctic macroplankton (*Euphausia superba*, *Themisto gaudichaudii* and *E. frigida*) (Madureira et al., 1993b). Lavery et al.(2007) used high-frequency (43,120, 200, and 420 kHz) acoustic scattering techniques to investigate dominant scatterers in mixed zooplankton populations. Earlier, Greenlaw (1977) described scattering from a fluid sphere on three species of dominant zooplankton (copepod, euphausiid and sergestid shrimp) in the surface and middle waters of the continental shelf off Oregon. Holliday and Pieper (1980) also measured with ultra-high-frequency between 0.5 and 3 MHz using acoustic volume scattering strengths in order to characterize zooplankton distribution in California current waters. MacLennan and Holliday (1996) explained three ideas from the discussion from Aberdeen Symposium in June 1995, Firstly, plankton scattering is sufficiently understood to conclude that present regressions used in acoustic are not good enough to provide good data of relationships between acoustical reflectivity and abundance, size, species and behavior of plankton. Secondly, acoustic instruments must sample plankton with high frequency resolution over a wide bandwidth in order to give useful data. Lastly, it is clear that the complex scattered sound of plankton includes information which could lead to useful estimates abundance and other parameters.

Comparison of the acoustic method and net sampling have been made for evaluating density and distribution of zooplankton and in order to determine a relationship between

acoustic volume scattering and the net sampled density, but also for estimating and predicting parameter like spicies composition, density, abundance, biomass, vertical and horizontal distribution. Sutor and Cowles (2005) determined the pattern of zooplankton distribution by comparing acoustic and net sampling at the continental shelf of Oregon, USA. They found that the composition of size and taxonomy of the zooplankton community had a strong effect on volume backscatter but also that the volume backscatter was not directly related to zooplankton biomass. Also, Johnson and Griffiths (1990) studied biomass and distribution of zooplankton with hydroacoustics and Bongo net in the Beaufort Sea. The relationship of net biomass and the 200 kHz volume scattering was stronger than for the 120 kHz and that the relationship of volume scattering with net biomass per m^3 were much stronger than the one for volume scattering against numbers per m^3. Therefore, with an inhomogeneous mixture of zooplankton, presence of animals in the net and physical water quality could cause difficulty in deriving a strong relationship between the acoustic volume scattering and zooplankton net biomass. Further, relationships between acoustic and biological sampling of zooplankton in the sound-scattering layer at the east coast of Oshima Peninsula, Japan was elucidated (Iida et al., 1996). S_V was measured at 25, 50, 100, and 200 kHz, while an Isaacs-Kidd Midwater Trawl (IKMT) and a North Pacific standard net (Norpac) were used to sample the biological organism in SSL. The relationship between the measured S_V and the biological density were calculated from IKMT sampling. They showed roughly a linear correlation at each frequency at 25 kHz and 100 kHz, but it was evident that different organisms groups had higher backscattering compared to others. Moreover, Kasatkina et al. (2004) explained comparisons of net and acoustic estimates of krill density in the Scotia Sea as difficult. They found that direct comparisons krill density from net and acoustic are revealed unsuitable at both small scale (i.e individual net tows) and at large scale (i.e regional surveys). The results of net and acoustic compared in term of krill distribution trends at large scale and the combined of net and acoustic data can be helpful in analysis of interannual trends of krill distribution variability at regional level. Postel et al. (2007) described zooplankton biomass variability off Angola and Namibia investigated by net samples and backscatter profile that show zooplankton biomass concentration ranges and horizontal distribution pattern obtained both methods as additional quality determinant. Hölter (2009) used 38, 70, 120 and 200 Simrad EK60 echosounders and biological sampling (krill trawl and makroplankton trawl) to study abundance, biomass and distribution of krill (*Euphausia superba*) and salp in the Antarctic Ocean.

Therefore, investigations of density and distribution of zooplankton with acoustics and net sampling may obtain different or similar results dependent on the organisms investigated, its distribution and size, but also with the purpose of study. Acoustic instruments have the ability to estimate density and rapidly map the distribution of dense and good scatterers at large scale, including horizontal and vertical distribution without disturbing the organisms. On the other hand, the net sampling method may with advantage be used when studying species composition, density and distribution on a smaller scale or in specific study areas.

The seamount "Hin Muang–Hin Daeng" is located on southeast part of Krabi province between 07^{o} 08.98′ N and 98^{o} 49.41′ E in the Andaman Sea. The maximum depth around the seamount is approximately 70 m. The seamount includes two seamounts "Hin Muang" with length about 200 m and width about 20 m. The peak of the seamount has a depth of about 8-12 m. Also, Hin Daeng has a second seamount located about 200 metres from the first one, where the peak is actually above surface with about 3 m. The Hin Muang–Hin Daeng seamount is one of Thailand's best dive sites in the Andaman Sea and comprises abundantly coral reefs and a richly marine community. Seamounts are particular areas of complex interaction between geography and ocean currents (Roden, 1987) and sometimes the biological communities characteristics are unusual relative to their neighboring waters (Boehlert and Genin, 1987; de Forges et al., 2000; Sassa et al., 2002). Several seamounts have increased biomass levels of zooplankton (Saltzman and Wishner, 1997), phytoplankton (Comeau et al., 1995; Genin and Boehlert, 1985), micronekton (Boehlert, 1988; Vereshchaka, 1995), demersal and pelagic fishes (Uchida and Tagami, 1984) and anthozoan corals (Genin et al., 1986). Current-geography interactions probably play an important role in structuring seamount communities. Also, changing flow disturbances including attached eddies, internal tides, and rotary flow may affect the local production around these structures. Also, a continuous flowing supply of new nutrients is favorable for the stationary community on the pinnacle, which may use less searching energy by only changing their position in the wake of the pinnacle (Loder et al., 1988; Noble and Mullineaux, 1989; Owens and Hogg, 1980).

The Andaman Sea is dominated by two monsoons; the southwest monsoon exists during May to October showing storms, heavy rainfall up to 2000 mm and stimulated sea. The northeast monsoon is active from November to April, and is characterized by clam and dry weather with about total 200 mm rainfall (Khokiattiwong, 1991). Limpsaichol et al. (1987) described the water quality along the southern part of the Andaman Sea, Phuket to Satun province as sea water influenced generally by runoff to high relative salinities which ranged from 32.6-32.8 ppt, dissolved oxygen 5.5-6.0 mg l^{-1}, pH 8.06-8.15, temperature 27.6^{o}- 29.3^{o}C,

with total suspended solid values of 9.9-14.8 mg l^{-1}. The nutrient values of nitrate and phosphate ranged from 0.120-3.402 and 0.082-0.872 µg-atom l^{-1}, respectively. Environmental parameters are important factors which can affect marine organisms, and particularly the planktonic larvae stages. Ocean current is one also a very important parameter, which may affect the life and behavior of marine organisms. Currents influence the variation of other hydrographic parameters, for instance the distribution of temperature, salinity as well as the marine mixing process of water masses and diffusion of nutrients and pollution initiated into the coastal water (Khokiattiwong, 1991). Moreover, sea current variation is natural factors affecting the movement and distribution of zooplankton. The tidal circulation in the Andaman Sea between Krabi and Satun province moves mainly in an elliptical pattern with displacement of 3 km scale, with water flow velocities less than 0.25 ms^{-1} (Pornpinatepong, 2005). In addition, the current speeds and directions along the shore line at the northern end of Kradan Island, Lanta Island and mainland of Krabi province showes constantly southwards flow over the entire water column with a speed ranging from 0.06 to 0.12 knots (Khokiattiwong, 1991).

The use of hydro-acoustic sampling method for studying density and distribution of zooplankton using hydro-acoustic sampling is new methodology in Thailand, introduced around 20 years ago. Generally, zooplankton investigations in Thailand have been made by Bongo nets with different mesh sizes of net which is towed horizontally, vertically or obliquely and has sampled large volumes of water (tens to thousands of cubic meters). Water samplers have been used to take discrete zooplankton sample at desired depth with relatively small volumes of water (a few liters). Andaman Sea Fisheries Research and Development Center (personal communication) studied abundance of pelagic and demersal fish around on a seamount using acoustic surveys with 38 kHz and 200 kHz echo sounders in 2006 and 2009, the abundance of fish found was to be about 3000 kg and 7000 kg, respectively. Whereas, zooplankton density in the Andaman Sea by Bongo net and water sampler was ranging from 1075-51258 individuals m^3 Copepoda was dominant taxon accounting for over 50% of total zooplankton. (Nootmorn et al., 2007; Patarajinda et al., 2007; Satapoomin and Pornchai, 2002).

The Hin Muang–Hin Daeng seamount is also a specifically selected sampling area for studying density and distribution of zooplankton using the acoustic method with supporting biological sampling for management of fisheries resources in the Andaman Sea. The objectives of this master thesis are as follows:

- Assess abundance and distribution of zooplankton on a seamount using acoustic methods and biological sampling
- Compare abundance and distribution of zooplankton using acoustic method and biological sampling

2. Materials and Methods

2.1 Survey Area

The survey was carried out with the Andaman Sea Fisheries Research and Development Center vessel RV "Pramong 4" in 3 cruises during monsoon period from 14^{th}-17^{th} of August 2010, 14^{th}-17^{th} of September 2010 and 26^{th}-30^{th} October 2010 during day time and night time. The survey area covered around the Hin Muang–Hin Daeng seamount located on southeast part of Krabi province between 07^{o} 08.98′ N and 98^{o} 49.41′ E in the Andaman Sea, Thailand (Figure 2.1)

Figure 2.1 *The survey area, Hin Muang–Hin Daeng seamount in the Andaman Sea, Krabi province, Thailand.*

2.2 Acoustic Sampling

The acoustic surveys were conducted using SIMRAD EK60 echo sounder split beam transceivers at 38 and 200 kHz, mounted on the hull of the vessel. The echosounders were calibrated in Andaman Sea during the second sampling cruise. The ER60 software was used to display the data during the cruise. The settings and calibration data of the echo sounders are found in Table 2.1:

Table 2.1. *Technical specifications and calibration parameters for the echo sounder.*

Transducer type	ES38B	ES200-7C
Transmission frequency	38kHz	200 kHz
Transmission power	2000 W	150 W
Estimated speed of sound	1542 $m \cdot s^{-1}$	1542 $m \cdot s^{-1}$
Absorption coefficient	5.31 $dB \cdot km^{-1}$	81.22 $dB \cdot km^{-1}$
Pulse duration	512 μs	512 μs
Band width	3.28 kHz	5.97 kHz
Angle sensitivity	21.90 dB	23.0 dB
Vertical resolution	9.9 cm	9.9 cm
Equivalent beam angle	-20.6 dB	-20.7 dB
TS Transducer Gain	-23.51 dB	-26.02 dB
3 dB beam width	7.06° / 6.95°	6.8° / 6.60°

The acoustic data were collected on four transects crossing the seamount in a "star" pattern. The distance of each transect was 6 nautical miles in day time and night time (Figure 2.2). The cruise started from the northwest passing the seamount to southeast (transect line 1, 07° 11.08′ N, 98° 47.03′ E to 07° 06.81′ N, 98° 51.49′ E) turned to the south, ahead of the seamount to the north (transect line 2, 07° 50.94′ N, 98° 49.35′ E to 07° 11.95′ N, 98° 49.35′ E). Afterwards, we proceeded to transect line 3 which began northeast along to southwest across the seamount (07°11.04′ N, 98° 51.53′ E to 07° 06.85′ N, 98° 47.19′ E) and revolved to the west passing the seamount to the ending point on the eastern side (transect line 4, 07° 08.95′ N, 98° 46.33′ E to 07° 08.95′ N, 98° 52.37′ E).

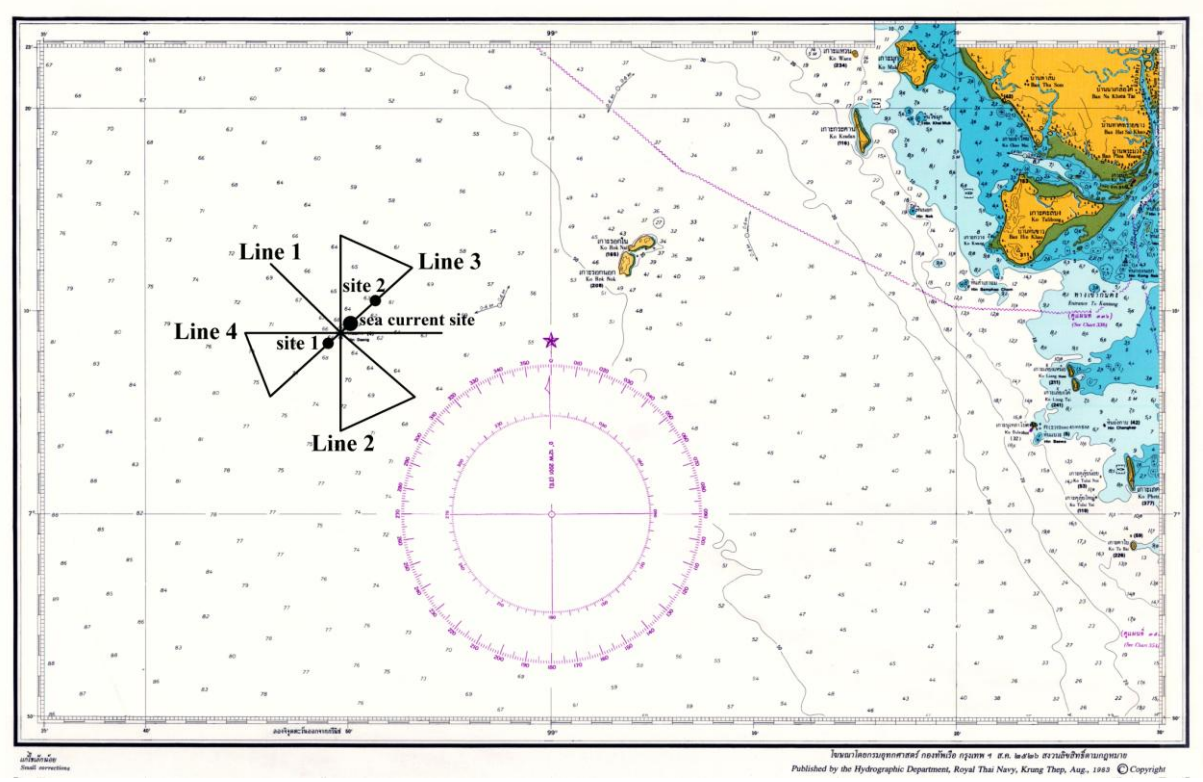


Figure 2.2 *A map showing the transects crossing the seamount in star pattern, with the two selected biological sampling sites and the sea current sampling site.*

2.3 Biological Sampling

The biological data was collected at 2 sampling sites placed on transect line 3 of acoustic sampling: Site 1 (07^{o} 08.55′ N, 98^{o} 48.92′ E) indicates the area near to the seamount, 0.5 nautical miles distance, and Site 2 (07^{o} 10.16′ N, 98^{o} 50.64′ E) shows the area far from the seamount, at 1.5 nautical miles distance (Figure 2.2).

Two sampling gears were used to study the abundance and distribution of zooplankton. The Bongo net was the main gear for studying of mesozooplankton and fish larvae. The diameter of this net was 60 cm with 330 μm mesh size in the cod end, equipped with a flow meter and depth sensor (Pi) (Figure 2.3). The Bongo was towed horizontally a vessel speed of maximum 2 knots for 15 minutes, repeatedly for each 10 m depth interval from surface to maximum depth in daytime and night time. The samples were split into two halves by a splitter (Motoda, 1959). Half of the sample was preserved in a 4% neutral formalin seawater solution. This part was further used for species identification. The other half was filtered through 330 μm mesh plankton net for zooplankton dry weight biomass determination.

Additionally, a Van Dorn 20 liters water sampler (Figure 2.4) was applied for studying of microzooplankton. The 20 liters of water were collected every 5 m from the surface to 20 m. Deeper than 20 m, samples were collected at 10 m intervals. The water samples were filtered through 50 μm mesh plankton net and fixated in 4% neutral formalin seawater solution.

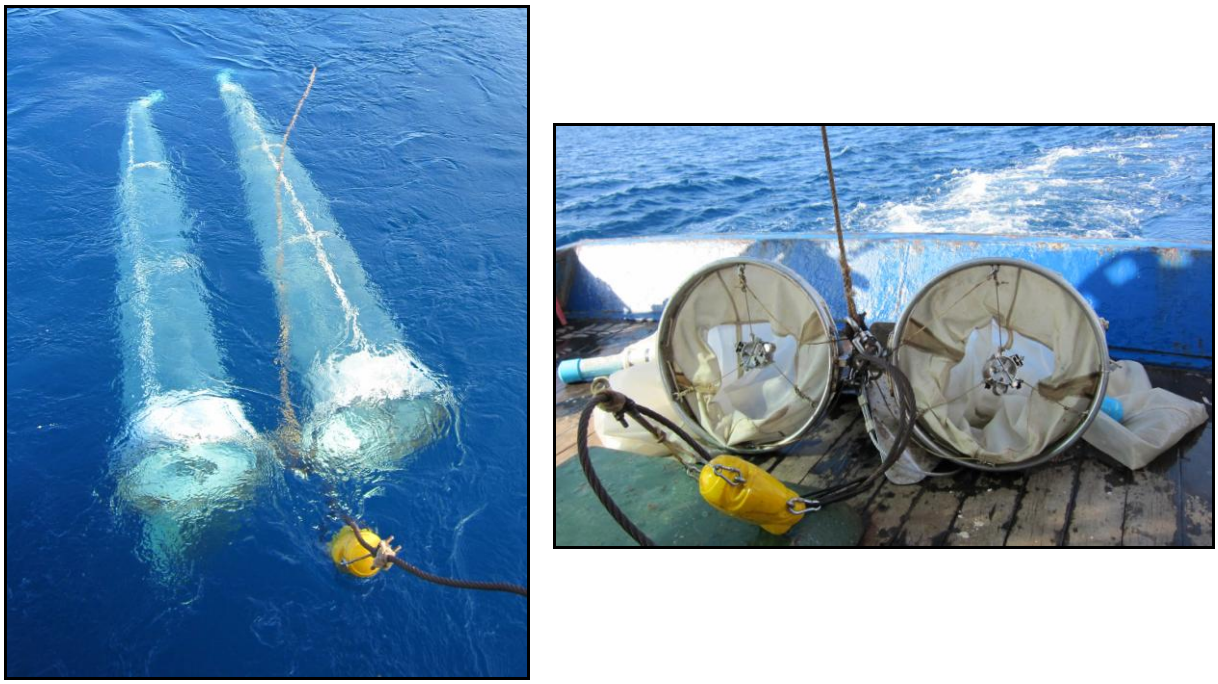


Figure 2.3 *The 60 cm diameter Bongo nets during retrieval. Flow meter and depth sensor is shown in front of the nets.*

Figure 2.4 *The Van Dorn 20 liters water sampler.*

2.4 Environmental Data

Oceanographic parameters were collected with CTD SBE 19 plus SeaCat Profiler (Figure 2.5) produced by Sea-Bird Electronics Inc. (Sea-Bird, 2007). Salinity, temperature, dissolved oxygen and pH were recorded for each meter throughout the water column at Sampling Site 1 and Site 2 during the cruise all three cruise.

Figure 2.5 *Photo of the CTD SBE 19 plus SeaCat Profiler.*

Additionally, sea current data were sampled by digital mini current meter SD-6000 Sensordata (www.saivas.no, 2011) was set as Figure 2.6 and collected at sampling site (07^{o} 09.75′ N, 98^{o} 50.24′ E) about 0.5 nautical miles from the seamount (Figure 2.2).

CTD and sea current data were transmitted with cable to a computer and post-processing program. SSBEDataProcessing software by SeaTeam version 1.50 (Sea-Bird, 2007) and sea current data processing from ASCII files by SD6000 version 4.3.8.31 (www.saivas.no, 2011). All data file was converted to the Microsoft Excel format and the statistical analysis was performed with MYSTAT 12, A student version of SYSTAT, Systat Software (2011).

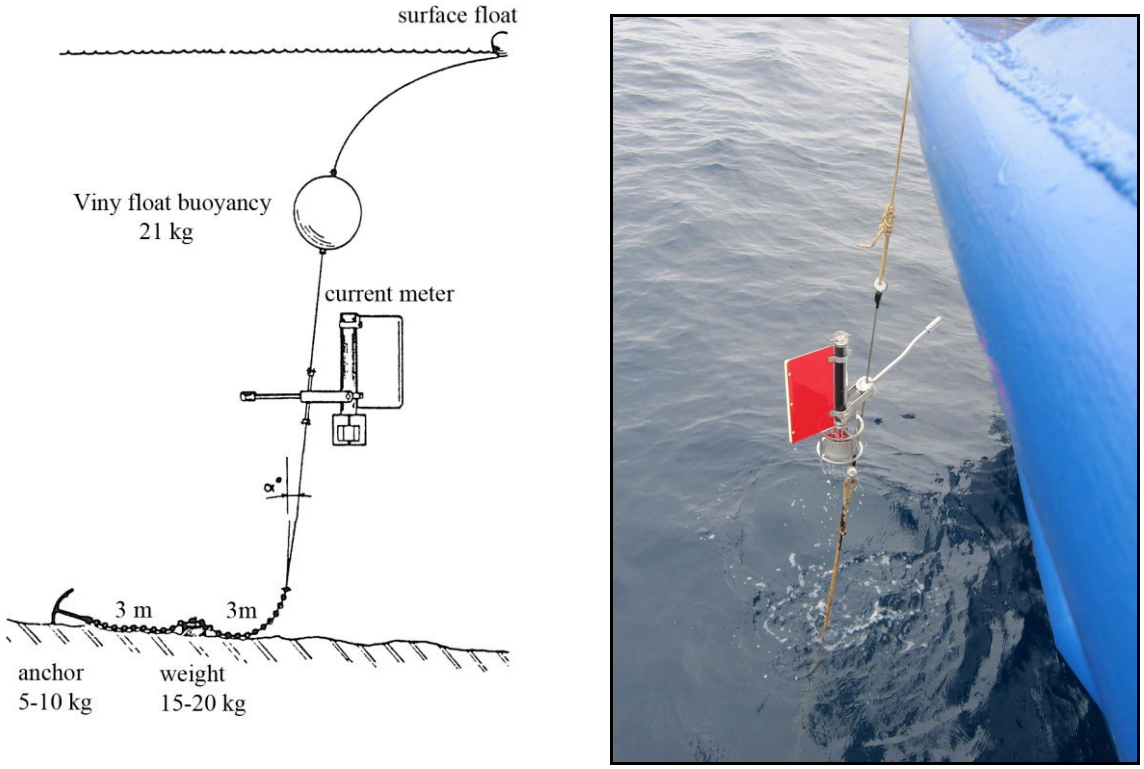


Figure 2.6 *Mini current meter SD-6000 Sensordata.*

2.5 Data Analysis

2.5.1 Zooplankton analysis

The samples were analyzed at the zooplankton laboratory of the IMR. The zooplankton samples collected with the Bongo net were filtered through 180 μm mesh size and rinsed formalin out with freshwater. Larger representatives include cnidarians, chaetognaths, euphausids, decapod larvae, cirripedia larvae, echinodermata larvae, amphipoda and polychaeta using an open counting chamber of 6.5 cm x 6.5 cm. The counting and identification were made under a binocular dissecting Leika stereo microscope at proper magnification. For dense samples, zooplankton fraction of less than 180 μm is separated from the larger ones by filtration and subsampled with a wide bore pipette for an aliquot of 1-5 ml for counting and further identification in a counting chamber under a stereo microscope according procedures described by; Boltovskoy (1999a, 1999b), Chayakul (1996), Conway et al.(2003), Davis (1949), Kasturirangan (1963), Leis and Carson-Ewart (2000), Mauchline (1998), Mulyadi (2002; 2004) Phukham (2008), Suwanrumpha (1987), Wongrat (1998) and Wuttichareonmongkol (2004).

The density of zooplankton as number per m^3 was based on the formulas:

$$\text{Zooplankton density (ind./m}^3) = \frac{N}{V_B}$$

Where N = number of the zooplankton individual

V_B = volume of water passed through the plankton net (m^3)

$$V_B = n \times M \times a$$

n = revolution number recorded by the flow meter

a = surface area of the net opening (m^2)

M = constant of displacement (m) per 1 revolution;
(calibrated on each cruise)

Zooplankton samples collected with the Van Dorn 20 liters water sampler were treated differently. All the formalin fixed sea water samples (100 ml bottles) were once again filtered through 50 μm mesh size and the formalin washed out with freshwater for counting and further identification in a counting chamber placed a stereo microscope. Foraminifera, cnidaria, polychaeta, gastropoda, bivalvia, echinodermata, marine cladocera, ostracoda, calanoida, cyclopoida, poecilostomatoida, harpacticoida, chaetognatha, urochordata and fish larvae were identified procedures described in the literature; Boltovskoy (1999a, 1999b), Chayakul (1996), Conway et al.(2003), Davis (1949), Kasturirangan (1963), Leis and Carson-Ewart (2000), Mauchline (1998), Mulyadi (2002; 2004) Phukham (2008), Suwanrumpha (1987), Wongrat (1998) and Wuttichareonmongkol (2004).

The density of zooplankton as individual per m^3 was based on the formulas:

$$\text{Zooplankton density (ind./m}^3) = \frac{N}{V_V} \times 1000(\text{liters} / \text{m}^3)$$

Where N = number of the zooplankton individual

V_V = volume of water collected by Van Dorn sampler (20 liters)

Zooplankton length measurement were derived from subsamples of copepod (calanoida, cyclopoida, poecilostomatoida and harpacticoida) which were the dominant groups with highest density at all sampling sites. Samples were scanned and sized size by a ZooScan system with ZooProcess and Plankton Identifier (PkID) software version 6.16 (Gorsky et al., 2010). The copepod subsamples were rinsed for formalin with tap water and then some boiled fresh water was poured on the scanning tray to evenly covered it. The frame was placed on the foremost left-bottom side of the scanning tray, and the sample with some boiled water was added until the border of frame was reached. Separation of copepods by pouring the sample homogeneously on the tray was necessary. If some copepods were still floating, they were tried sunk by manual manipulation. Afterward, the Zooprocess was launched and scanned sample with the ZooScan system for subsequent analysis according to instructions in (Garcia-Comas, 2010) (Figure 2.7).

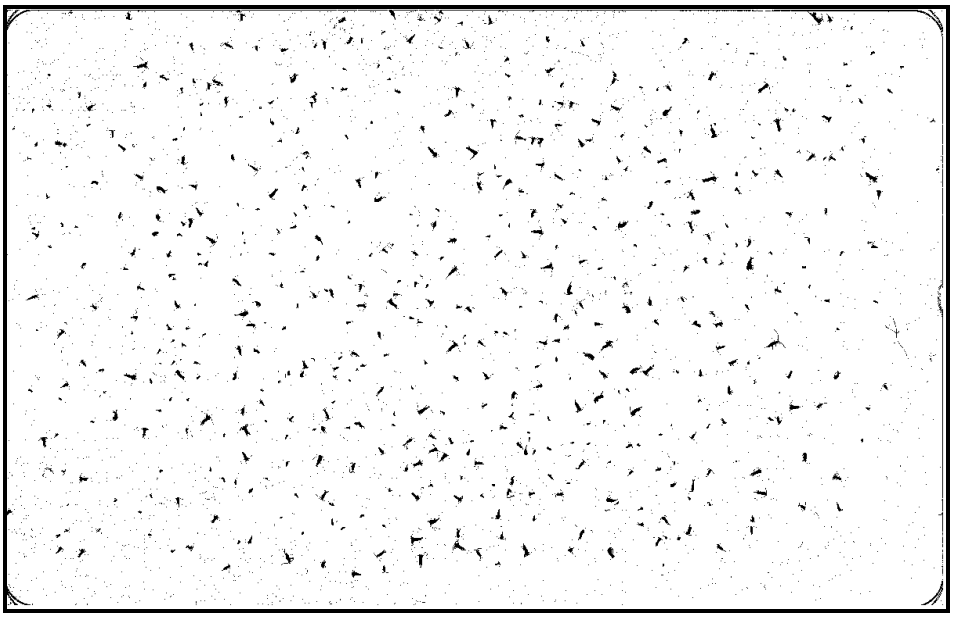


Figure 2.7 *A scanned copepod picture from the ZooScan system.*

In addition, half of the zooplankton from the Bongo net collection was frozen ex situ, and later processed for dry weight measurements. The samples were dried at 60℃ for 24 hours in drying chamber (heater) and cooled in a desiccator for one hour weighing.

The zooplankton dry weight biomass determination was determinated as follows:

$$\text{Biomass (mg /m}^3\text{)} = \frac{\text{dry weight(mg)}}{V_B}$$

Where V_B = volume of water had passed through the plankton net (m^3)

$$V_B = n \times M \times a$$

n = revolution number recorded by the flow meter

a = surface area of the net opening (m^3)

M = constant of displacement (m) per 1 revolution

2.5.2 Acoustic analysis for zooplankton density estimation

The raw data stored by the 38 and 200 kHz Simrad EK60 echo sounder were post-processed and scrutinized using software Large Scale Survey System (LSSS) (Korneliussen et al., 2006; www.marec.no). The abundance of fish and zooplankton was estimated from the volume backscattering strength, S_v, at two frequencies, recorded on transects covering the sampling area. During the scrutinizing process, data for a selected distance where thresholded (filtered) in amplitude, S_v, ranging from -80 dB to -50 dB, at both 38 and 200 kHz for enhancing or removing echoes from fish and plankton. To exclude the unwanted target like echoes from fish, a thresholding from the top of the amplitude distribution can be done in LSSS in a similar manner as thresholding from the bottom of the S_v scale when removing weak targets. A combination of these two techniques was used in order to extract and separate plankton and fish targets. Plankton shows weak backscattering while fish shows much stronger backscattering on the recorded echogram. Afterwards, separated and processed data at both frequencies were stored in each nautical mile (nmi) with a vertical resolution of 5 m. The lower depth limit was 100 m and the upper limit was set at 5 m below sea surface. The conversion factor between s_v, and the area backscattering coefficient, s_A, are given by the expression

$$s_A = 4\pi \times 1852^2 \int_{z_1}^{z_2} s_V dz \qquad \text{(Knudsen, 1990)}$$

with unit: $m^2/n.mi^2$, z_1 and z_2 are the layer limits and s_V is volume backscattering coefficient.

The scattering cross section of a single zooplankton organism (σ_{sp}) is calculated from the target strength (TS) equation of the species. The target strength is a measure of how strongly one individual copepod reflects sound and the relationships between TS and its back scattering cross section is:

$$TS = 10\log(\frac{\sigma_{sp}}{4\pi}) \quad \text{and} \quad \sigma_{sp} = 4\pi \times 10^{(TS/10)} \qquad \text{(MacLennan et al., 2002)}$$

The abundance of zooplankton can be made by the equation:

$$\rho_A = \frac{< s_A > A_0}{< \sigma_{sp} >} \qquad \text{(Ona, 1999)}$$

Where ρ_A is the area density (#/nmi^2), $<s_A>$ is mean area backscattering coefficient (m^2/nmi^2), A_0 is an elementary area of the region being surveyed (nmi^2) and $<\sigma_{sp}>$ is the mean scattering cross section of a representative individual zooplankton organism.

Copepod is the dominant group at all the sampling sites. Their total length was automatically measured by using the ZooScan system (Gorsky et al., 2010). In addition, 300 scanned individuals were manually measured in order to validate the automatic zooscan measurements and for obtaining a relationship between total length and prosome length (Figure 2.8). The linear regressions between total length and prosome length is shown in Figure 2.9

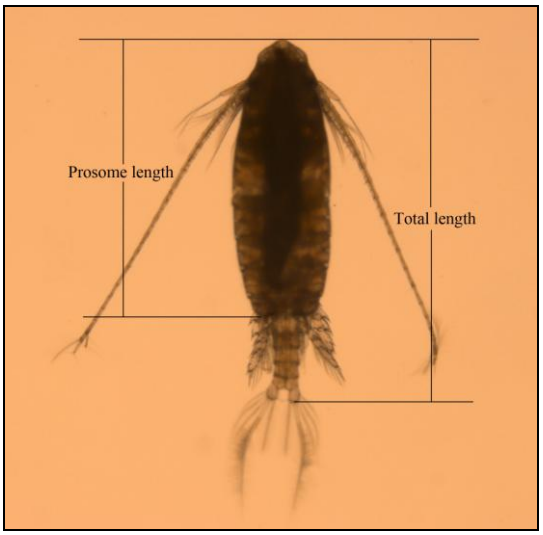


Figure 2.8 *Measurement of total length and prosome length of a copepod*

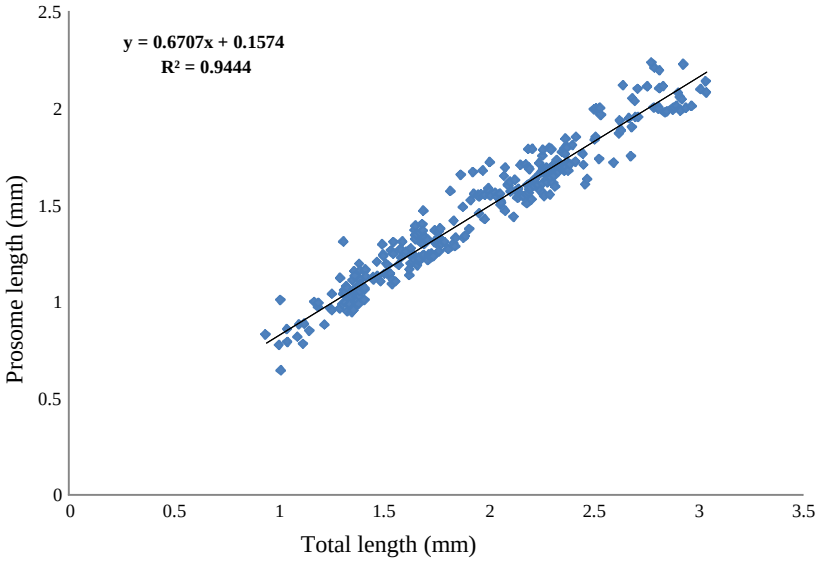


Figure 2.9 *Linear regression between measured total length and prosome length of 300 copepods.*

The shape of copepods is numerically expressed as a spheroid. However the simpler fluid sphere model might also be a satisfactory approximation for calculating the backscattering cross section (Holliday and Pieper, 1995).

For frequencies less than 1 MHz, Stanton and Chu (2000) found a good fit between experimentally measured mean TS and the mean TS computed from two different models (Figure 2.9). First, they obtained the mean TS of hundreds cultured copepods (*Pseudodiaptomus coronatus*) with a mean total length 0.94 mm and cephalothorax width 0.65 mm, freely swimming in the acoustic measurement volume but with known numerical density. The results were compared with target strength estimated by using the high resolution, shape-sensitive, Distorted-Wave Born Approximation (DWBA), but also the simpler sphere model (Anderson, 1950). From the figure 2.9, both models used a mean density contrast between the animal and surrounding sea water ($g=\rho_a/\rho_W$) and sound velocity contrast between the flesh and the surrounding sea water ($h=c_a/c_W$) of g=h=1.01 (homogeneous) and as an average over the measured distribution of lengths.

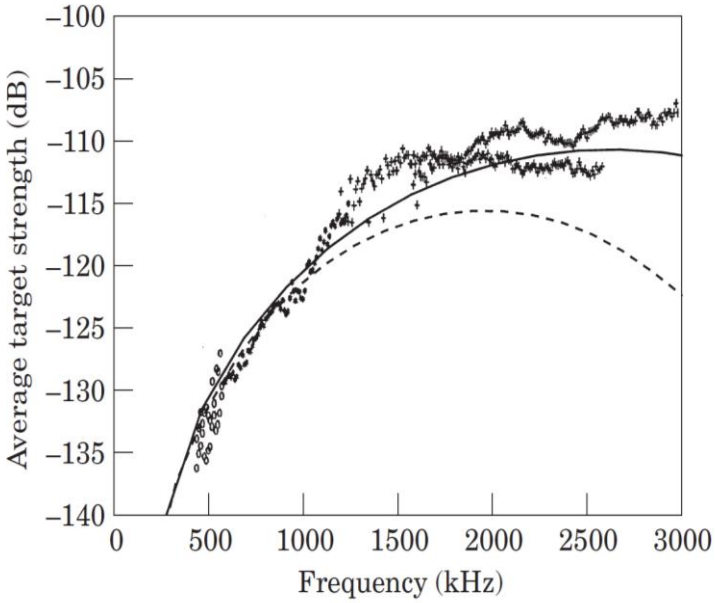


Figure 2.10 *Plot of mean target strength measured and two model calculations (Stanton and Chu, 2000) of copepods (Pseudodiaptomus coronatus). The solid line is the from the deformed finite cylinder model, using a smooth prorate spheroid shape and the dashed lines represents the sphere model of Anderson (1950).*

For this study, the target strength of copepods at 38 and 200 kHz were calculated by Dr. Lucio Calise, scientist in zooplankton acoustics at IMR. The fluid sphere model (Anderson, 1950) was used for the calculations. Calise (2009) explained that the Anderson model considers an irregular shaped fluid-like target to be acceptably described by a sphere containing an equivalent volume as large as the animal, but does not include other effects, like target shape. This gives an aproximate, but sufficient result for small targets like copepods, but not for larger, directional scatterers like euphausiids. However, it was the first instructive step in predicting the mean target strength of zooplankton fluid-like species even with more complex shapes (Foote et al., 1990; Greenlaw, 1977; Greenlaw, 1979; Greenlaw et al., 1980; Holliday and Pieper, 1980; Pieper and Holliday, 1984; Stanton et al., 1987).

The prosome length of copepod varied from 0.45-3.05 mm with steps of 0.1 mm. The density contrast (g) used was 1.0035 and sound speed contrast (h) with 1.019, both obtained from measurements by Matsukura et al. (2009). The estimated equivalent sphere radius (ESR) of 0.2173 mm was calculated by using the prosome volume-to-prosome length relationship, described by Knutsen et al. (2001) and Greenlaw and Johnson (1982). Also, the seawater physical properties included temperature (27.73-30.05°C) salinity (32.5 psu) and sound speed

(1544 m/s) were used. All parameter was input to the model for predicting the scattering from an individual fluid-like target.

The results of the computations of target strength of copepods between 0.45-3.05 mm at 38 and 200 kHz as shown in Table 2.2. The target strength of 1kg copepods were further obtained from TS estimate and the weight of the copepods, based on the weight/length relationship reported for tropical copepods (Chisholm and Roff, 1990).

***Table 2.2**: Estimated target strength (TS) of copepods between 0.45-3.05 mm with 38 and 200 kHz.*

Prosome length (mm)	Estimated ESR (mm)	TS at 38 kHz (dB)	TS at 200 kHz (dB)	N/kg individuals	TS/kg at 38 kHz	TS/kg at 200 kHz
0.45	0.09	-191.4	-162.5	273347078	-107.0	-78.2
0.55	0.11	-185.7	-156.9	147034887	-104.0	-75.2
0.65	0.14	-181.0	-152.2	87748324	-101.6	-72.8
0.75	0.16	-177.0	-148.2	56389962	-99.5	-70.7
0.85	0.18	-173.5	-144.7	38303338	-97.7	-68.9
0.95	0.21	-170.4	-141.6	27162839	-96.0	-67.3
1.05	0.23	-167.5	-138.8	19937292	-94.5	-65.8
1.15	0.25	-165.0	-136.3	15051673	-93.2	-64.5
1.25	0.28	-162.6	-134.0	11632931	-92.0	-63.3
1.35	0.30	-160.5	-131.8	9170854	-90.9	-62.2
1.45	0.32	-158.5	-129.9	7353837	-89.8	-61.2
1.55	0.35	-156.6	-128.0	5984339	-88.8	-60.3
1.65	0.37	-154.8	-126.3	4933052	-87.9	-59.4
1.75	0.40	-153.2	-124.7	4112951	-87.1	-58.6
1.85	0.42	-151.6	-123.2	3464021	-86.2	-57.8
1.95	0.45	-150.2	-121.8	2943975	-85.5	-57.1
2.05	0.47	-148.7	-120.4	2522445	-84.7	-56.4
2.15	0.50	-147.4	-119.1	2177240	-84.0	-55.8
2.25	0.52	-146.1	-117.9	1891895	-83.4	-55.1
2.35	0.55	-144.9	-116.8	1654022	-82.7	-54.6
2.45	0.57	-143.7	-115.7	1454179	-82.1	-54.0
2.55	0.60	-142.6	-114.6	1285085	-81.5	-53.5
2.65	0.62	-141.5	-113.6	1141068	-81.0	-53.0
2.75	0.65	-140.5	-112.6	1017661	-80.4	-52.6
2.85	0.67	-139.5	-111.7	911319	-79.9	-52.1
2.95	0.70	-138.5	-110.8	819202	-79.4	-51.7
3.05	0.72	-137.6	-110.0	739017	-78.9	-51.3

As evident from the table, the target strength of a single copepod is extremely low at 38 kHz, or about -170 dB for an animal with 1 mm prosome length while the target strength at 200 kHz is nearly 1000 times stronger, -140 dB. Even at 200 kHz, the echo is too weak for detection of a single individual, and multiple targets in the resolution volume is necessary for detecting copepods as echoes above the acoustic background noise level.

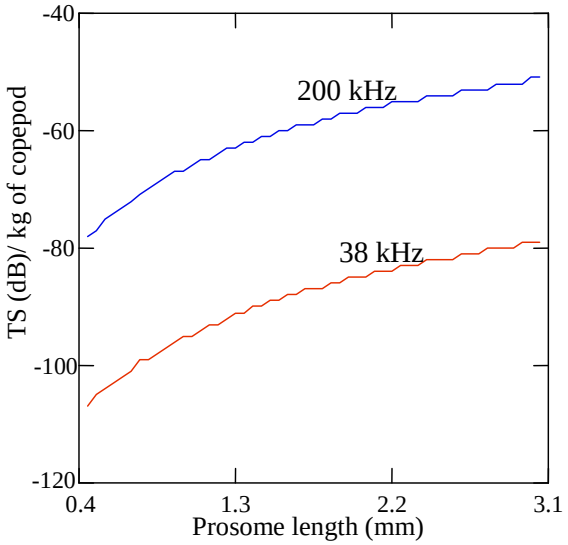


Figure 2.11 *The target strength (dB) of 1 kg copepods between 0.45-3.05 mm at 38 kHz and 200 kHz.*

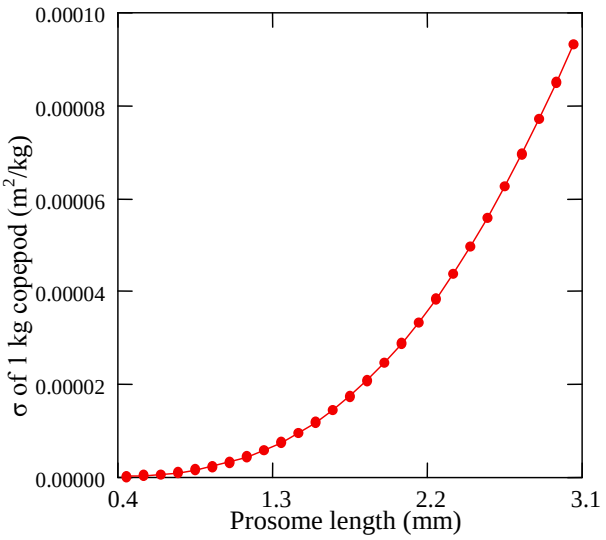


Figure 2.12 *The backscattering cross section, (σ_{sp}), (m^2/kg) of copepods at 200 kHz as a function of size.*

The equivalent spherical radius (ESR) is the radius of a sphere, which means that the backscattering versus size may increase proportionally with close to r^3, or close to the animal volume (Ciekals, 2011; Holliday and Pieper, 1995; Holliday et al., 1989; Pieper and Holliday,

1984; Pieper et al., 2001; Stanton and Chu, 2000). These means that the backscattering may increase exponentially with the size of the copepod.

$$\sigma \sim ESR^3 \sim V$$

The relationship: $\sigma \sim L^3$ and $\sigma = kL^b$ from nonlinear regressions and the weight-length relationship $W=aL^b$ may be combined, since the σ–W relationship should then be less sensitive to size.

The length–weight relationship for copepodes; ln W= 3.09 ln L-19.19 (Chisholm and Roff, 1990) was used to calculate the weight of individual copepods. This equation was derived from studies on tropical copepods. Therefore, the scattering sound of 1 kg of small copepods should not very different from 1 kg of larger copepods.

Since the large copepods in a mixture contribute more to the backscattering than the small ones, a representative size for the backscattering is computed: This length was determined the cube root mean cubic length (CMCL, in mm) of the prosome length by:

$$CMCL = \sqrt[3]{\frac{\sum n_i L_i^3}{\sum_{i=1}^{n} n}}$$

This length is slightly larger than the mean length of the size distribution, but more representative for calculating the mean backscattering cross section for the population.

Further, in our analysis, the target strength of the fish on the pinnacle were not directly measured, but we adopted a general TS to length relationship for swimbladdered fish $\overline{TS} = 20 \log L - 68$ (dB; close to the one suggested by Foote (1987) for fish with closed swim bladders).

2.5.3 Statistic

Data management, restructuring and formatting were done in Microsoft Excel. Statistic analysis and all graphical presentations were accomplished with MYSTAT 12, A student version of SYSTAT, Systat Software (2011).

3. Results

3.1 Environmental data

Dissolved oxygen in the water column at Site 1 was between 2.57–4.60 mg/l (Figure 3.1a) throughout the study period. In August the oxygen levels was stable around 4.35-4.60 mg/l during daytime whereas a decrease from 4.45 to 2.87 mg/l was observed at bottom depth (60 m) in night time. The oxygen level in September was lower, but steady between 3.22-3.84 mg/l during both day and night. In the October survey, the oxygen concentration was nearly the same as in August in the upper 20 meters, 4.2 mg/l, but decreasing to its lowest value of 2.57 mg/l at 50 depths. Similar oxygen concentrations were recorded in the water column at Site 2 ranging from 2.49-4.49 mg/l (Figure 3.1a). The variability between the three surveys is also very similar, as expected at this close between the two sites. The lowest oxygen levels were seen in the September night station.

The recorded sea temperature was high, between 28^{o}C and 30^{o}C, in all three surveys at both sites (Figure 3.2.a, b). From a temperature of close to 30^{o}C in the surface in the August survey at both sites, a slight cooling to 29.8 and 28.6 30^{o}C is seen in the surface water in the September and October surveys. The temperature is also quite stable throughout the water column, with only a gradual decrease of 0.5 to 1.0^{o}C towards the bottom at 60 m. In two of the profiles, the lower 20 meters of the water column is 1.5 ^{o}C colder than the water above.

The salinity increased with depth throughout the sampling period. The range of salinity at Site 1 and Site 2 were 32.00-33.43 psu and 32.12-33.62 psu, respectively (Figure 3.3, a, b). In the August observations, the salinity increased slightly from surface to 20 m depth and further sharply to 30 m depth at daytime in both sampling sites indicating a layering effect, but this is less pronounced during night in the same survey. A slight increase in salinity is seen from the August to the October survey, but the general rising salinity throughout the water column to 60 m depth is similar for both sites in the three surveys.

The sea water acidity, measured through its pH value, was stable throughout the water column for all sampling periods. The value at Site 1 ranged from 8.28-8.52. The pH in August at day and night was constant between 8.28-8.44 although, there was a sharp decrease from 40 m to 60 m depth at night time. If we use Site 2 (Figure 3.4 b) as a reference, a gradual increase in pH is seen from the August survey to the October survey in the whole water column, from 8.4- in August to slightly more than 8.5 in October.

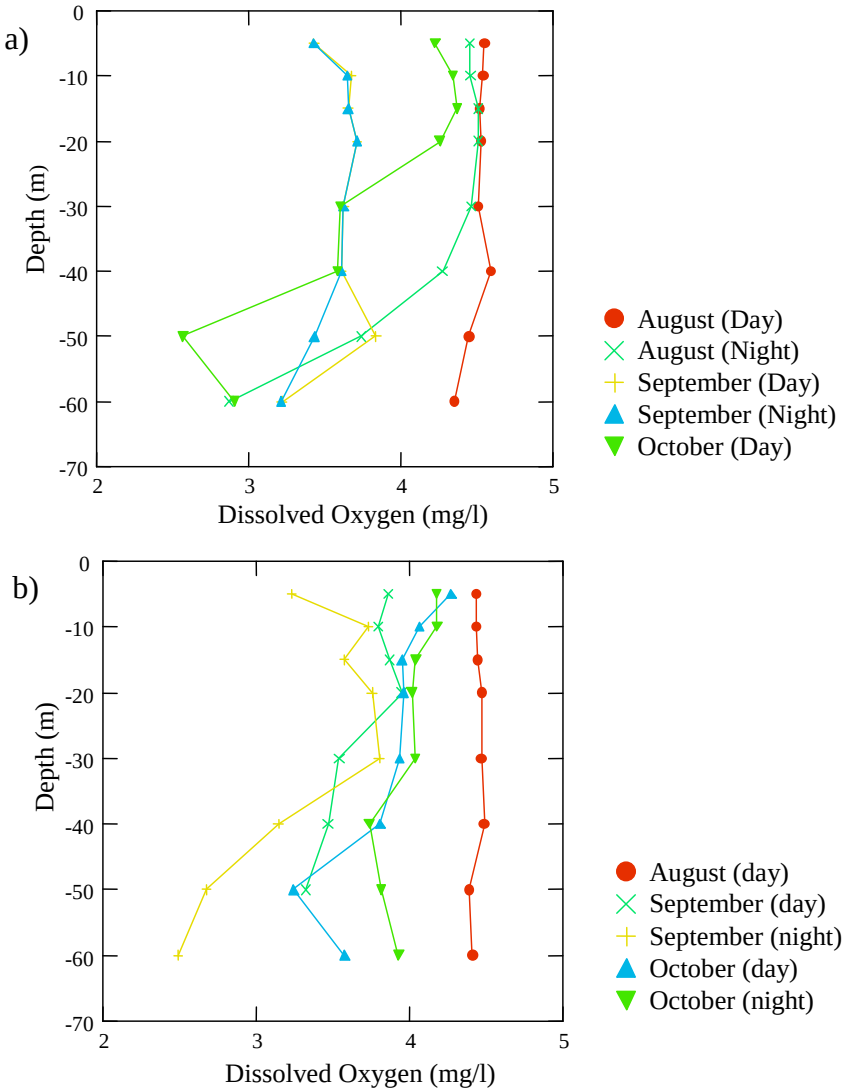
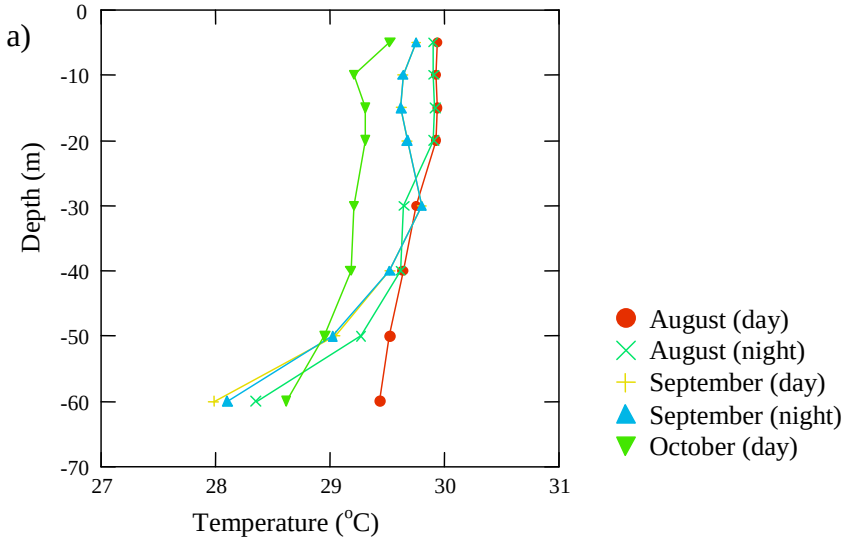


Figure 3.1 *Dissolved oxygen in mg/l at Site 1 (a) and Site 2 (b) for both the daytime and nighttime surveys.*



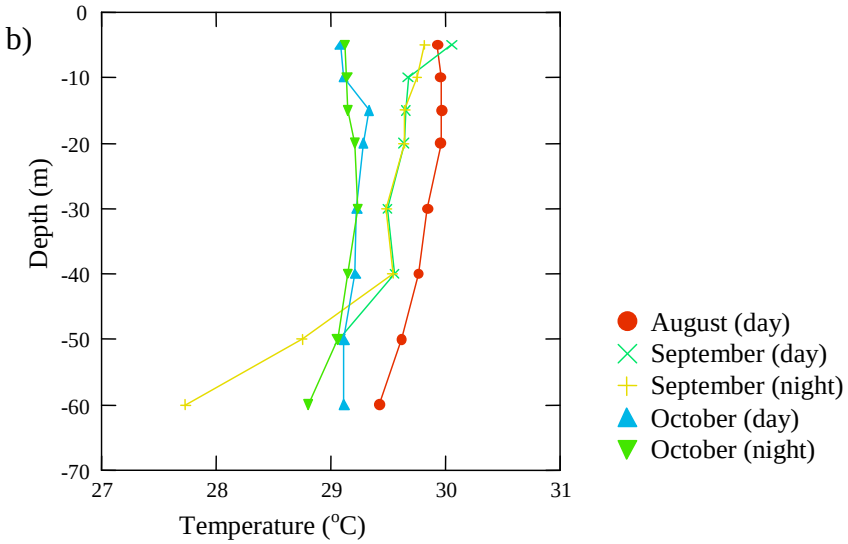


Figure 3.2 *Temperature (°C) at Site 1 (a) and Site 2 (b) for all three surveys.*

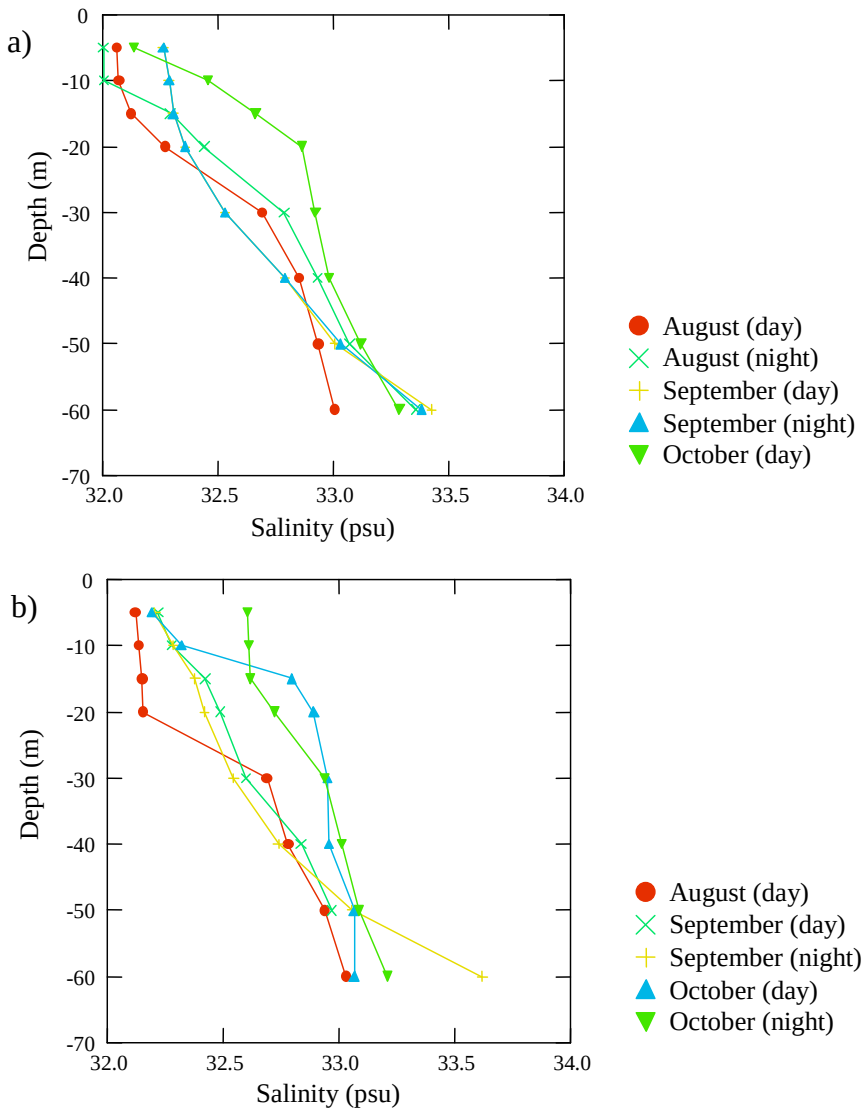


Figure 3.3 *Salinity (psu) at Site 1 (a) and Site 2 (b) for all surveys.*

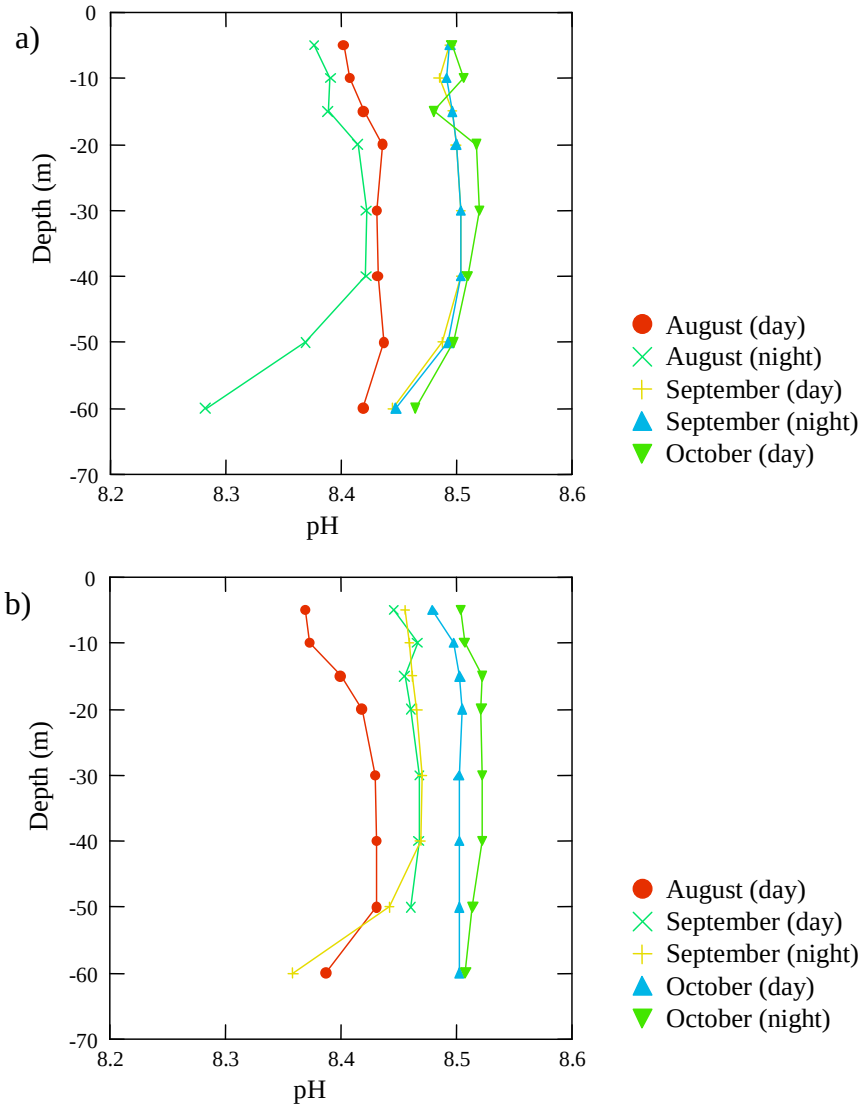


Figure 3.4 *pH values at Site 1 (a) and Site 2 (b) for all surveys.*

The sea current data were measured at north east, 0.5 nautical miles from the seamount. The current in August at 30 m depth (middle depth of the water column) was measured for 21 hours. The current speeds, direction and patterns are shown in Figure 3.5. The current speed ranged between 0.6-17.6 cm/s, with a change every 6 hours, corresponding to tidal cycles. The peak speeds recorded were around 17 cm/s for two periods and with nearly zero current speed in the two slack periods. A vector or particle plot (Figure 3.5) shows the character of the tidal movement in the area. There is mainly an east-west movement during the tidal cycle, but with a stronger northward resultant. The total northward movement over the 21 hour measurement period is less than 2.5 km.

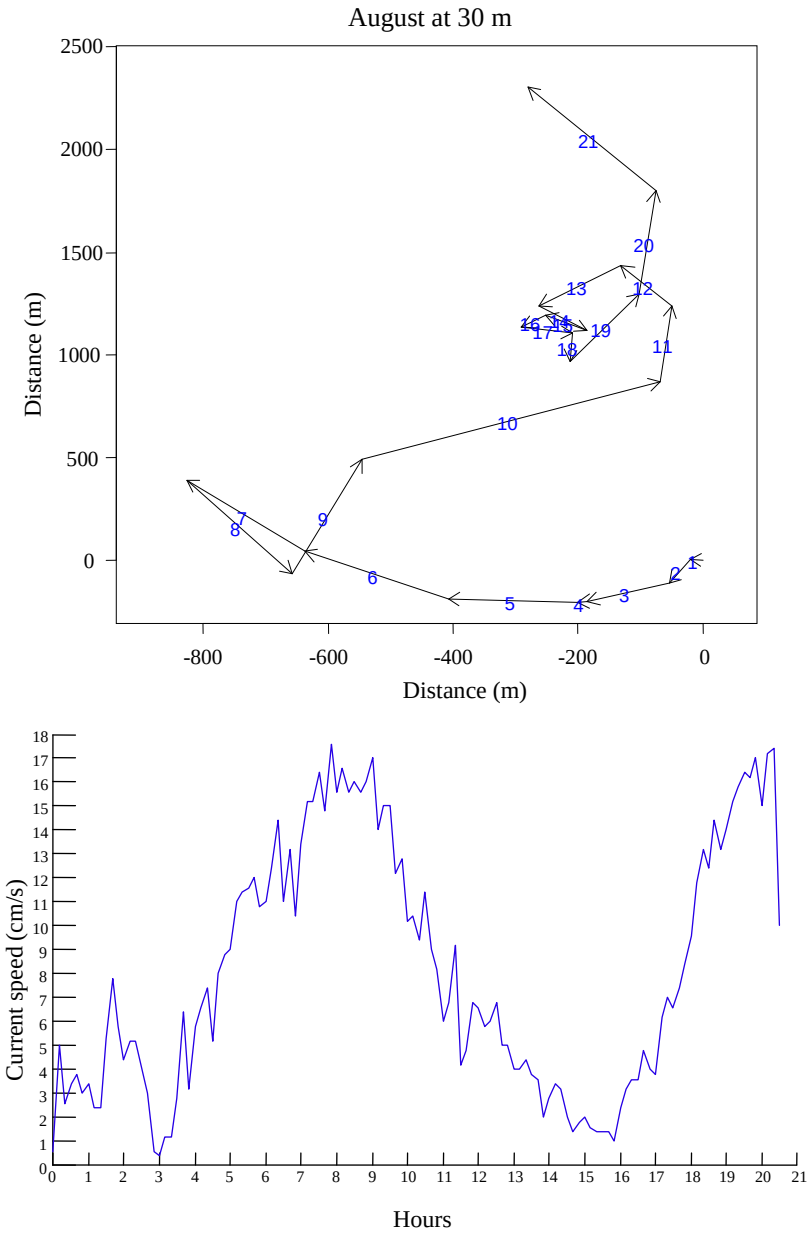


Figure 3.5 *Measured current speed at 30 m depth in the August survey over 21 hours. Current vector plot is shown above.*

Similarly, in the September survey, the current at 55 m (bottom) depth was measured for 26 hours. The speed now varied between 1.6 and 16.4 cm/s, (Figure 3.6), but with a less clear tidal cycle. From the vector plot, also here the east-western tidal pattern is clear, and with a total northward movement of about 1.5 km over the 26 hour measurement period.

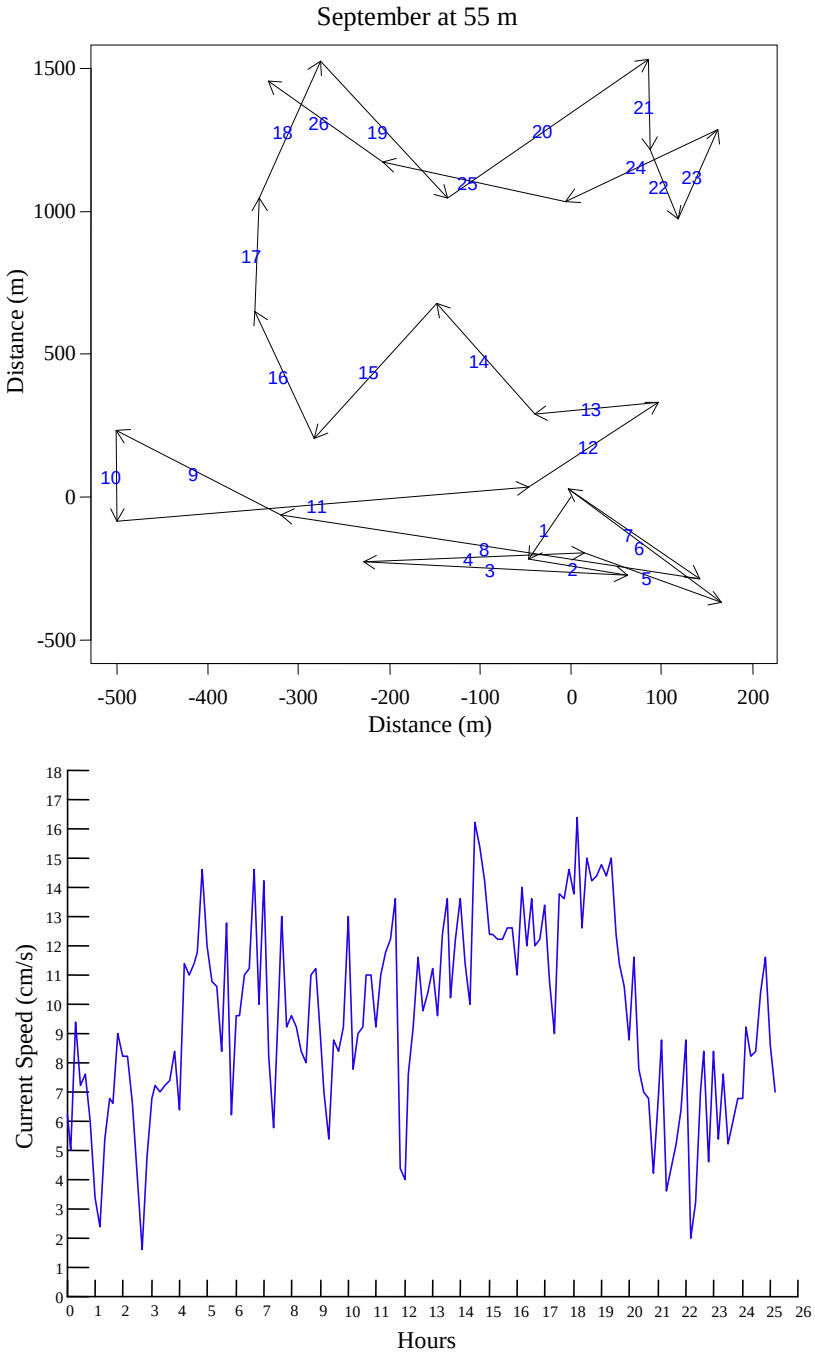


Figure 3.6 *Measured current speed at 55 m depth in the September survey over 21 hours. Current vector plot is shown above.*

Further, the current meter in the October survey was again located at 30 m depth, measuring for 23 hours. The speed current now varied between 4.4 and 21.8 cm/s, also in a similar clear cyclic pattern as recorded in August. However, the current speed in the slack periods was higher, 5–8 cm/s, and the maximum current speed was also higher, 21.8 cm/s.

The vector plot shows the same east-west movement, but now the total movement is in the opposite direction, southwards, and slightly further, about 3.0 km over 23 hours.

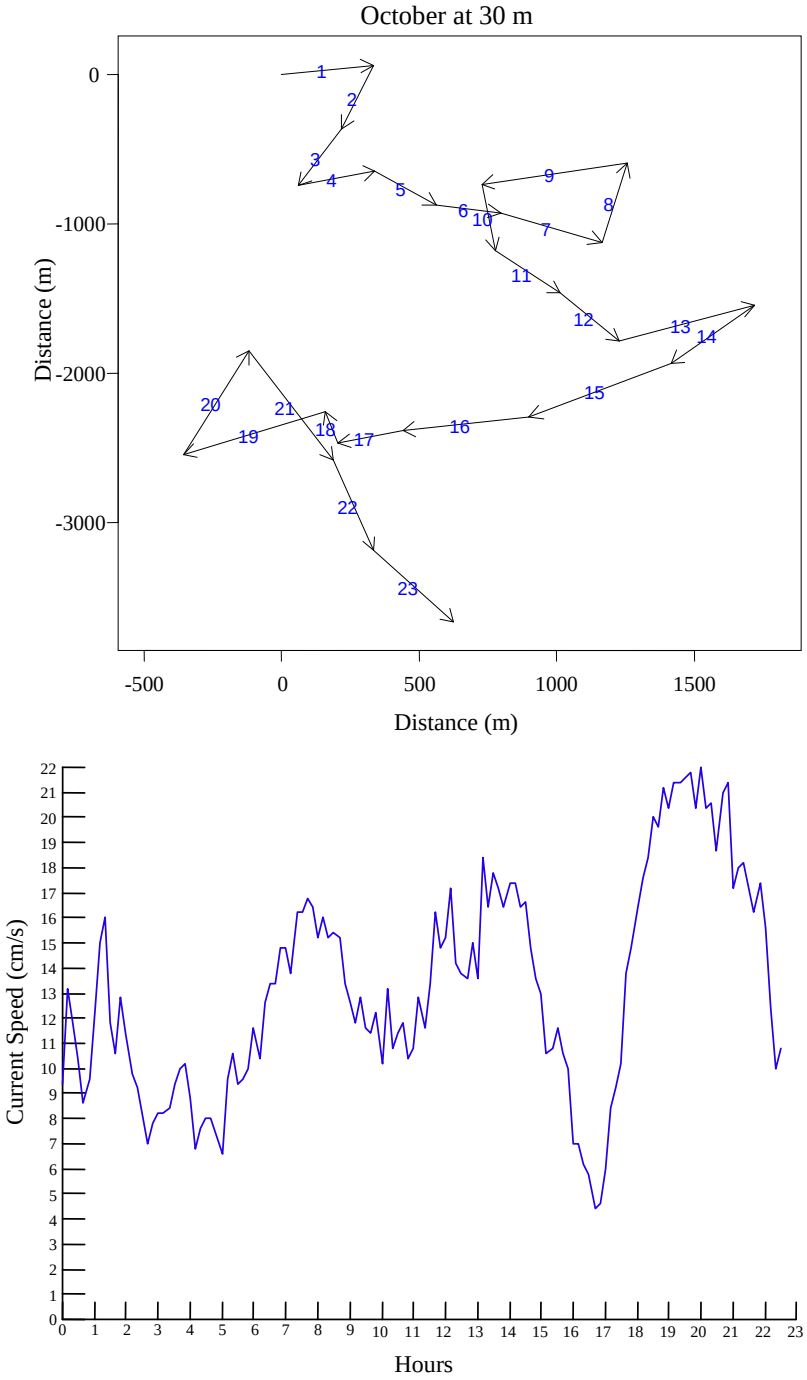


Figure 3.7 *Measured current speed at 30 m depth in the October survey over 23 hours. Current vector plot is shown above.*

3.2 Acoustic Survey data

3.2.1 Plankton density and distribution around the seamount

The acoustic data was collected on four transects crossing the seamount in a star pattern. The distance of each transect was about 6 nautical miles. The study area was repeatedly surveyed in 3 months between August-October 2010, and a full coverage both during daytime and nighttime was conducted if the weather condition permitted. Transect line 1 started from the northwest passing the seamount towards southeast. Transect line 2 was began at the south, ahead of the seamount towards north. Transect line 3 was went from northeast across the seamount towards southwest and at last, transect line 4 was continued from west, passing the seamount to the ending point in the east.

The acoustic data and echograms were analyzed with LSSS and showed acoustic density, (the mean area backscattering coefficient, $s_{A,}$ with units: m^2/nmi^2) in 10 meter thick layers along the transect line for data recorded at two echo sounder frequencies, 38 and 200 kHz. When scrutinizing the echograms, bottom echo errors and noise were first removed, and the echoes from zooplankton and fish separated into two scrutinizing categories: PLANKTON and FISH. The data were furthered stored to database with a resolution of 0.1 nautical miles (185.2 m) and 10 meter depth layers. At this stage the PLANKTON category contains all echoes resembling backscattering from zooplankton at both frequencies, (See echograms in Figure 3.14–3.17, later).

The mean area backscattering coefficient for plankton at 38 and 200 kHz had similar and fairly stable values outside and around the pinnacle at about 0.5 nautical miles distance from the pinnacle itself (Figures 3.8 and 3.9). Among the 4 transects the density at 38 kHz ranged from 250 to 3500 m^2/nmi^2 in August at daytime while increasing in night time to 1700-5600 m^2/nmi^2. In September the densities were lower on all transect lines at daytime (340-1900 m^2/nmi^2) rising at night to between 520-3700 m^2/nmi^2**.** Further, in October the densities at daytime at 38 kHz were 180-3400 increasing to 880-3400 m^2/nmi^2 during nighttime.

A similar picture is also seen in the 200 kHz data, but with lower backscattering for the plankton category at this frequency. The measured density here varies from 80-1200 m^2/nmi^2 in August at daytime with an increase to about 300 to 2000 m^2/nmi^2 at night. In September, the densities were low both day and night, 100-500 and 160-750 m^2/nmi^2, respectively. Further, the density in October during daytime varied from 40 to 900 m^2/nmi^2, rising slightly at night to 330-1200 m^2/nmi^2.

The horizontal distribution of the plankton category in September and October showed at both frequencies a similar pattern at all transect lines, and with a sharp decrease in density just over the seamount. The same pattern is also seen in some of the August transects, but not on all of them. Overall, the density of plankton was different between day and night all study periods both at 38 kHz ($\chi^2 = 507.954$, $p<0.001$) and 200 kHz ($\chi^2 = 782.875$, $p<0.001$).

The high backscattering at 38 kHz compared to 200 kHz may suggest that most of the backscattering of the plankton category may have been derived from gas bearing phytoplankton, rather than from zooplankton, but this will be dealt with later in the thesis, when comparisons with the biological sampling will be made.

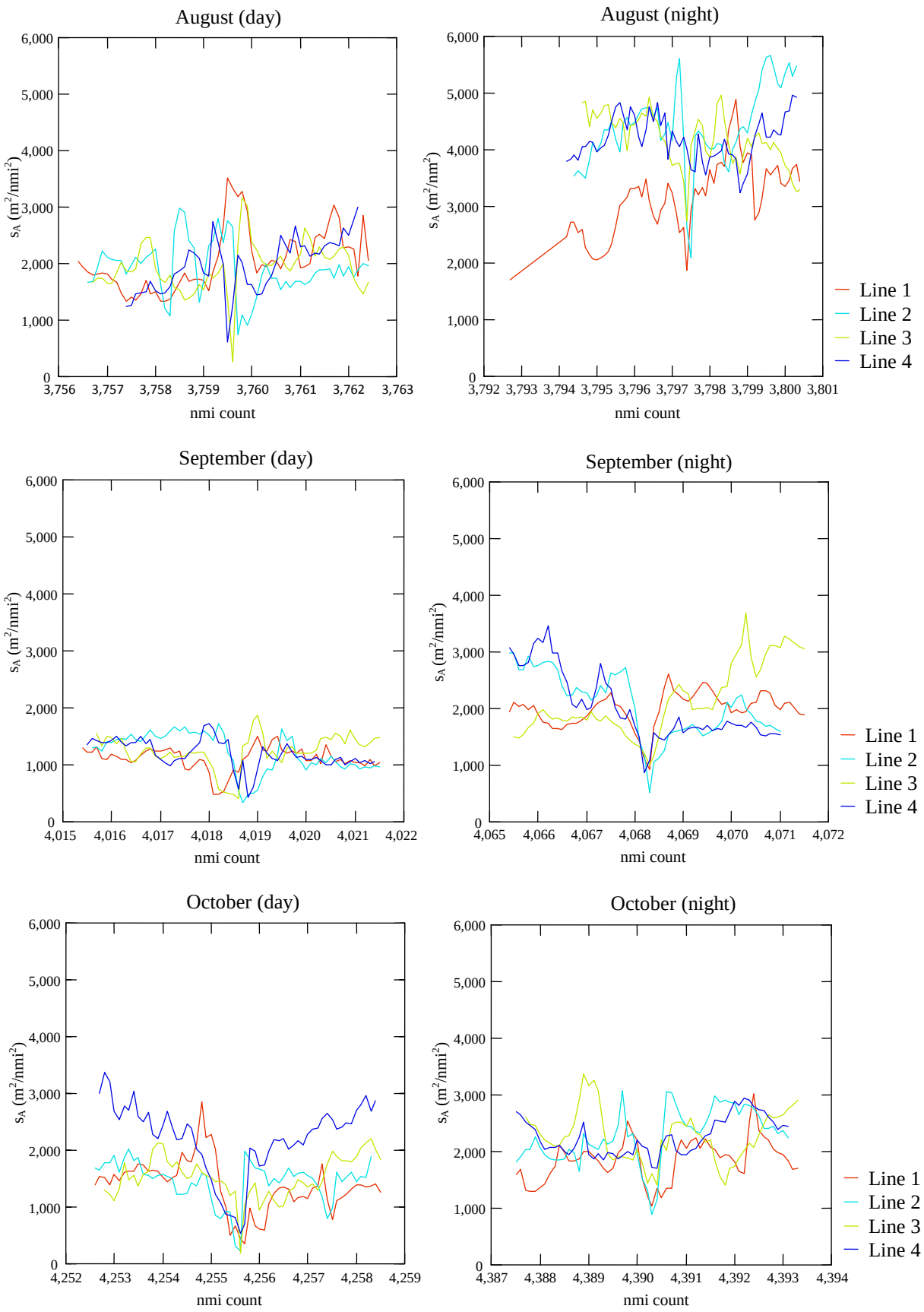


Figure 3.8 *The mean area backscattering coefficient of plankton at 38 kHz for all sampling periods.*

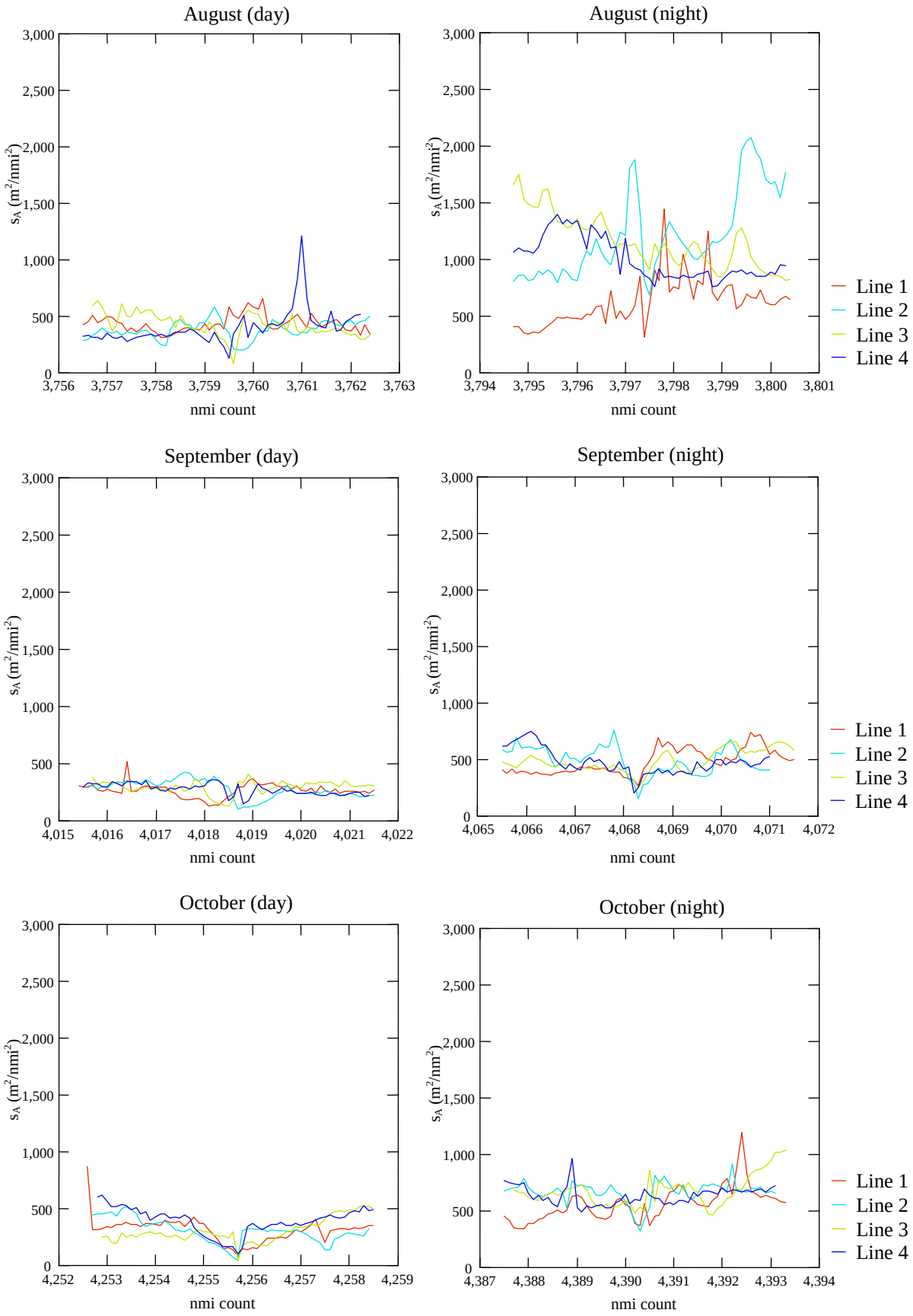


Figure 3.9 *The mean area backscattering coefficient of plankton at 200 kHz for all sampling periods.*

3.2.2 Plankton density at the pinnacle and outside of the pinnacle area

On most of the echograms, the density of the plankton layer seemed to be reduced close to the pinnacle. One way of investigating if this is significant is to calculate the mean density of plankton close to the pinnacle, and compare this with the mean density further away from the pinnacle. The mean density of plankton close to the seamount was usually lower than in the surrounding water masses for all study periods. At 38 kHz, the plankton density was significantly different between pinnacle and outside throughout study period (χ^2 = 37.145, p<0.001). It was also different both during daytime (χ^2 = 22.259, p<0.001) and night time (χ^2 = 27.706, p<0.001). See also Figure 3.10. These data are also equally supported by the 200 kHz data showing similar ratios. The data from the 200 kHz (Figure 3.11) also shows a significant difference between pinnacle and outside area densities for all sampling periods (χ^2 = 28.609, p<0.001). When day and night densities are separated, the differences are still significant: (χ^2 = 37.893, p<0.001 and χ^2 = 13.041, p<0.00, respectively). The mean differences for all transects are shown in Table 3.1 for both frequencies. In average the plankton category was in average 1.28 times larger outside the pinnacle area, than inside. Since we are measuring the mean area backscattering coefficient, the difference may be affected if the average depth on the transects through the inner area is smaller than in the outer area. When carefully inspected, the mean depth recorded over in the close to pinnacle area is 53 m ±6.15 m, while the integration was stopped at 60 m in the outer area. A small correction factor should therefore have been applied to the mean area backscattering for the inner area, corresponding in average to 60/53 = 1.13, or 9%. Still, the mean is lower, reflecting the lower density seen in the echograms.

Table 3.1 *Plankton acoustic abundance (m^2/nmi^2) between 0.5 nmi at pinnacle and outside of the pinnacle area.*

Frequency	August				September				October			
	Day		Night		Day		Night		Day		Night	
	Outside	Pinnacle	Outside	Pinnacle	Outside	Pinnacle	Outside	Pinnacle	Outside	Pinnacle	Outside	Pinnacle
38 kHz	1944	2135	4020	3518	1221	844	2148	1256	1711	907	2217	1651
200 kHz	412	343	1001	890	283	227	498	315	345	170	652	541

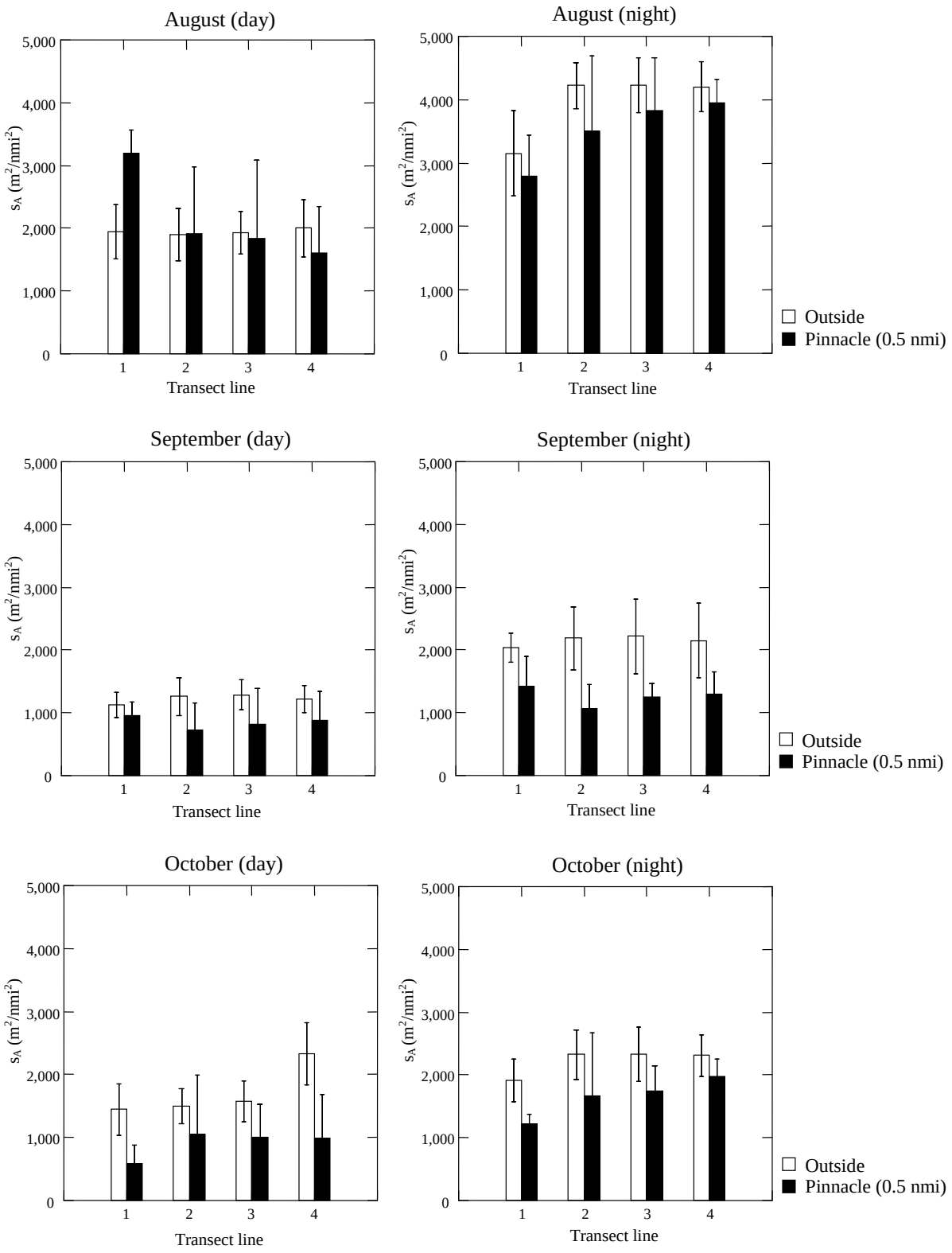


Figure 3.10 *Plankton density at 38 kHz between 0.5 nmi at pinnacle and outside of the pinnacle area. Standard deviation is shown.*

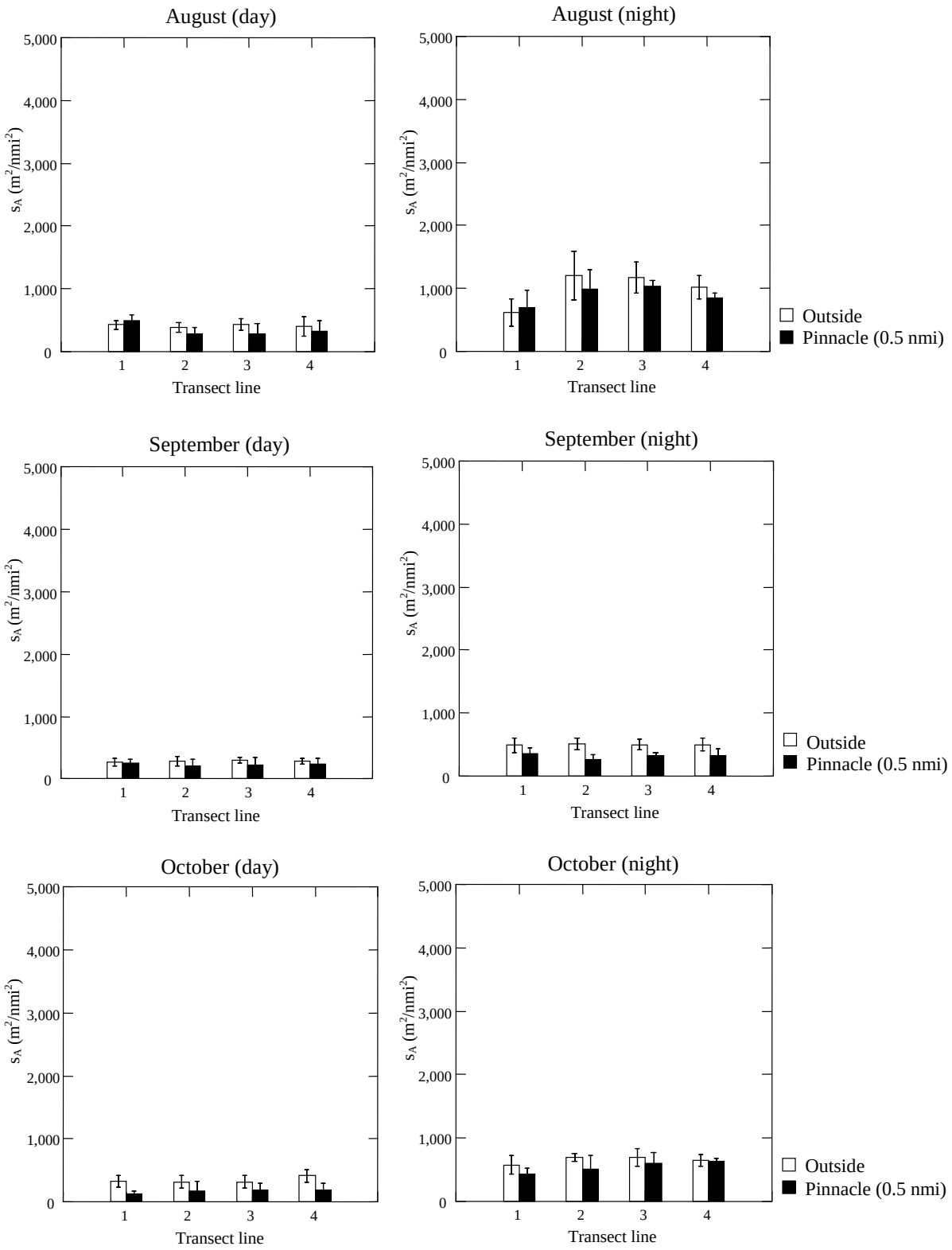


Figure 3.11 *Plankton density at 200 kHz between 0.5 nmi at pinnacle and outside of the pinnacle area. Standard deviation is shown.*

3.2.3 Fish density at pinnacle and outside of pinnacle areas

Based on the echograms scrutinized, the fish in the area was schooling very close to the pinnacle. Actually, 98% of the recorded backscattering from fish at both frequencies was found closer than 0.1 nautical miles from the pinnacle center. At 38 kHz, the density of fish was significantly different between a selected inner area, reaching out to 0.1 nmi from pinnacle and the outer area (from 0.1 to 0.5 nmi from the pinnacle center) throughout study period (χ^2 = 63.257, p<0.001). Additionally, at day the difference was also significant (χ^2 = 46.701, p<0.001) as well as at night time (χ^2 = 18.703, p<0.001). At daytime in August, the average density of fish was very high at the pinnacle at line 3 and 4 with a backscattering of 11200 and 12100 m^2/nmi^2 while density of at outside was found in line 1 and line 4 about 45 and 524 m^2/nmi^2, respectively. This means that only a small fraction of the fish was found, mainly along the bottom, outside the pinnacle area. The difference between the densities recorded on the different track lines merely reflects on which side of the pinnacle the fish was distributed at that particular moment, and how this was hit by the survey track line. A more ideal mapping of the fish distribution at the pinnacle could have been made by increasing the number of track lines, and reducing the time between each line. However, this was not the main objective of this thesis, and the fish densities obtained should only be used as an index of fish abundance.

With the above comment in mind, Figure 3.12 and 3.13 show that the density is clearly higher at the pinnacle for all surveys, day and night at both frequencies. The recorded mean density of fish is however slightly lower during the night coverage than during daytime. The statistic testing however, showed the difference to be insignificant (p = 0.17). Table 3.2 shows the computed biomass of different surveys. The density is higher in August than September and October at 38 kHz while at 200 kHz, the biomass in September is higher than August and October. From this variability we may assume that the actual density is not different between the three periods.

Table 3.2 *Fish acoustic biomass (m^2/nmi^2) between the 0.2 nmi at pinnacle and 0.8 nmi outside the pinnacle area of different surveys.*

Frequency	August				September				October			
	Day		Night		Day		Night		Day		Night	
	Outside	Pinnacle	Outside	Pinnacle	Outside	Pinnacle	Outside	Pinnacle	Outside	Pinnacle	Outside	Pinnacle
38 kHz	142	6499	35	2804	90	3425	136	5116	172	6745	59	911
200 kHz	156	3867	24	1721	36	2975	56	3532	116	4814	51	538

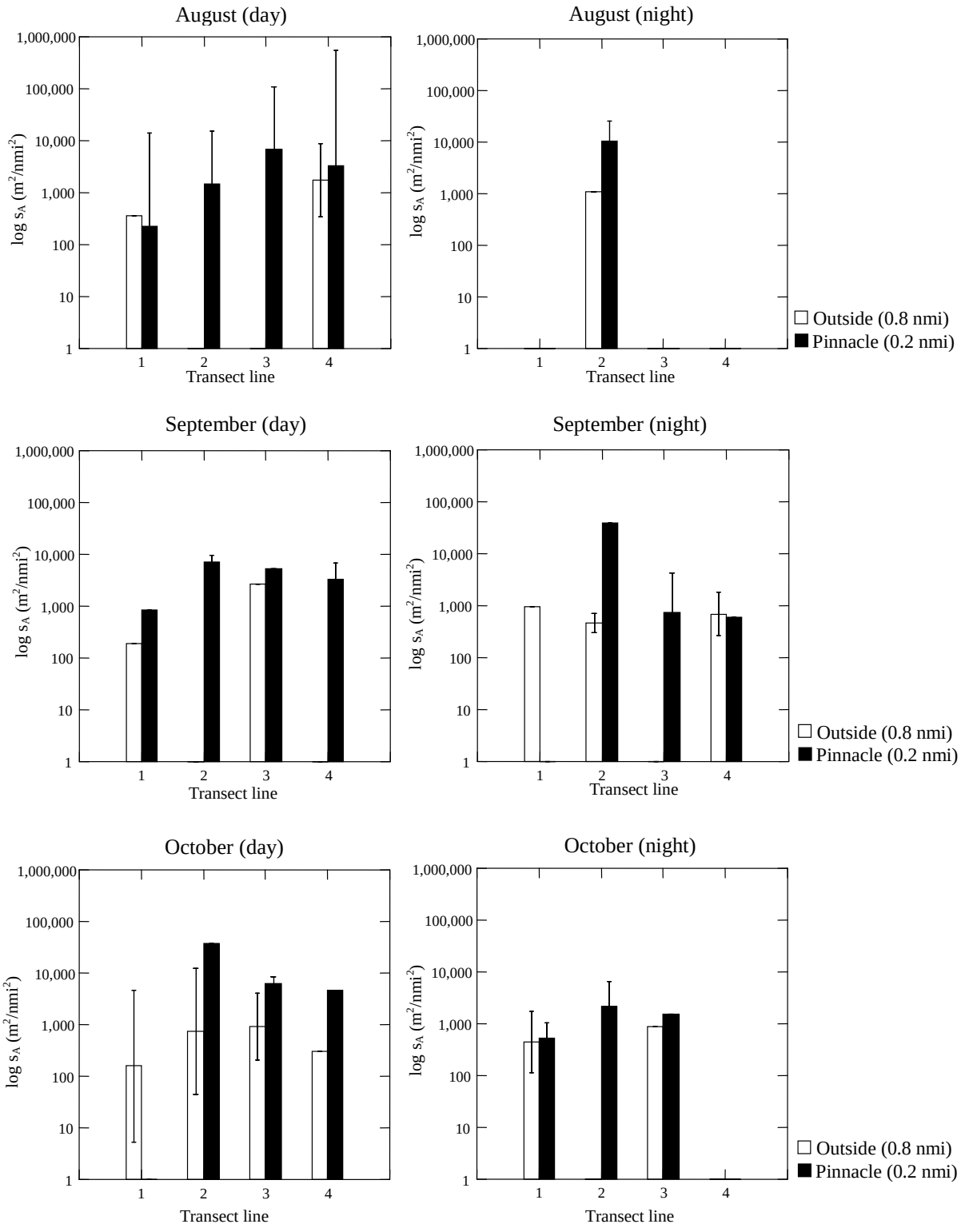


Figure 3.12 *Fish acoustic density at 38 kHz between the 0.2 nmi at pinnacle and 0.8 nmi outside the pinnacle area. Note: y-axis: log n m^2/nmi^2. Standard deviation is shown.*

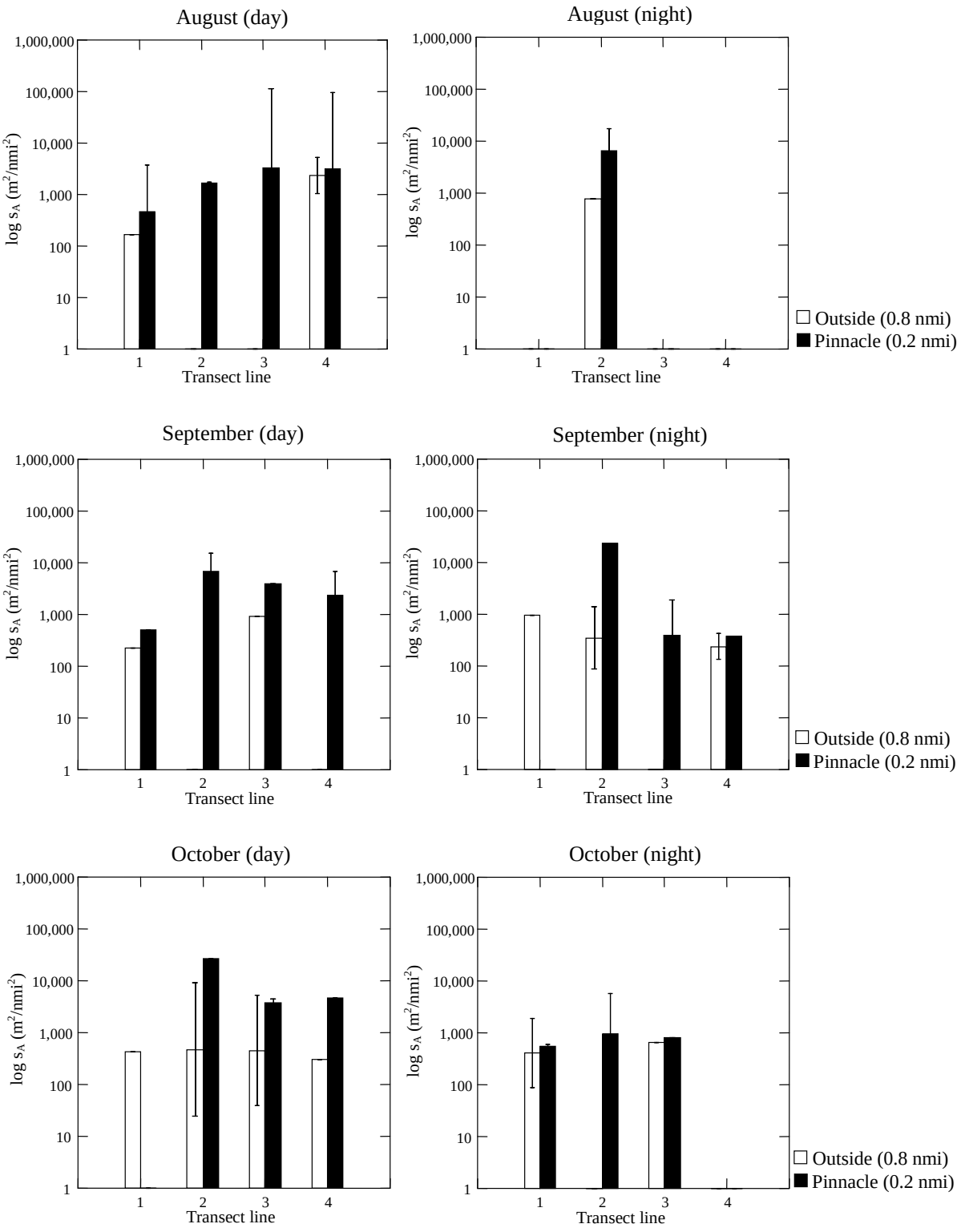


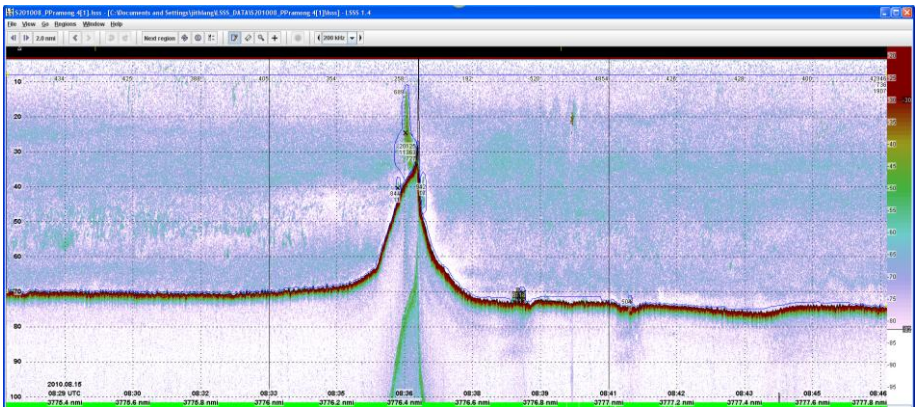
Figure 3.13 *Fish acoustic density at 200 kHz between the 0.2 nmi at pinnacle and 0.8 nmi outside the pinnacle area. Note: y-axis: log n m^2/nmi^2. Standard deviation is shown.*

3.2.4 Peculiarly selected echograms of zooplankton-like targets

During the survey and first post processing it was not clear if the scrutinized category PLANKTON was actually zooplankton.The main reason for this was the strong backscattering at 38 kHz compared to the 200 kHz, but also the general appearance of the backscattering at both frequencies. Several of the echograms revealed special cases to be presented, which is made here. The echograms represent different dense plankton layers where the layer depths change between day and night times throughout study period.

The first echogram (Fig 3.14) shows the measured plankton layers, the school of fish at the peak of the pinnacle, and the clear gap, or “hole” on the plankton layers just behind the pinnacle. The plankton layer-like structures continues out over the whole transect, beyond the 3 nautical miles shown here.

a)



b)

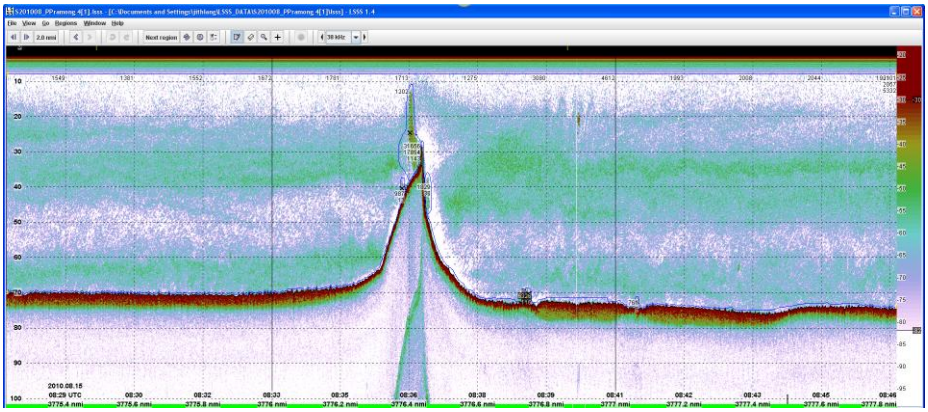
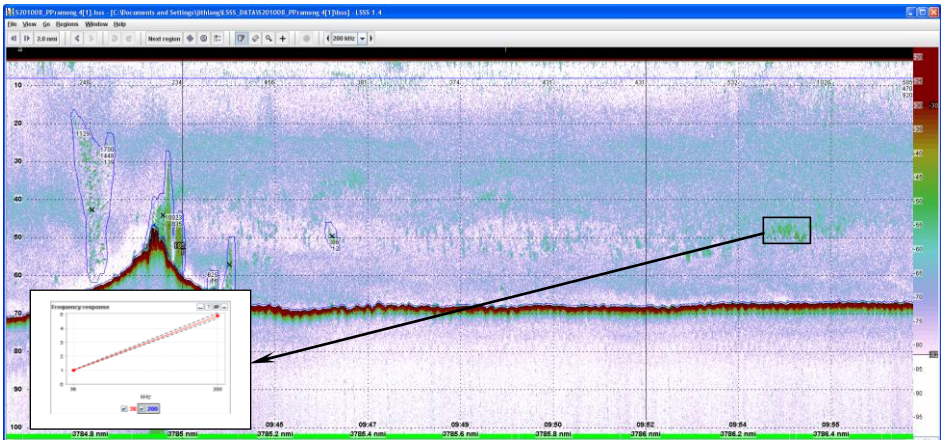


Figure 3.14 *Echogram picture of the gap in the plankton layer on the pinnacle at 200 kHz (a) and 38 kHz (b). The bottom depth outside the pinnacle is about 70 m, and the horizontal distance shown is about 3 nautical miles. (The finer grid is 0.2 nmi, 10 m depth layers).*

Second echogram (Fig 3.15) is sampled in August at daytime, on transect line 2 from about 2 nautical miles north of the pinnacle to 3 nautical miles west of the pinnacle on transect line 3. The echogram at 200 kHz showed the special characteristics of a typical zooplankton layer at 40-60 depth where the frequency response at 200 kHz is much higher than at 38 kHz. Also, the echogram at 38 kHz was not clearly showing this dense layer (Figure 3.15). It may also indicate that the zooplankton layer is more patchy distributed than earlier anticipated.

a)



b)

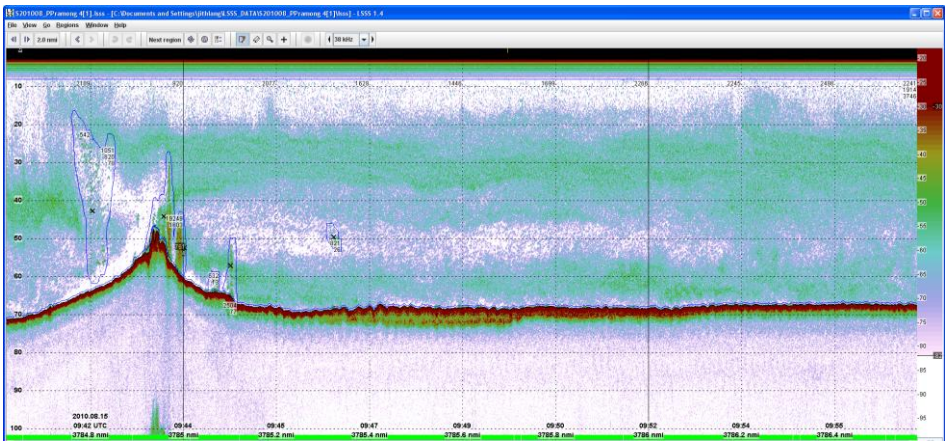
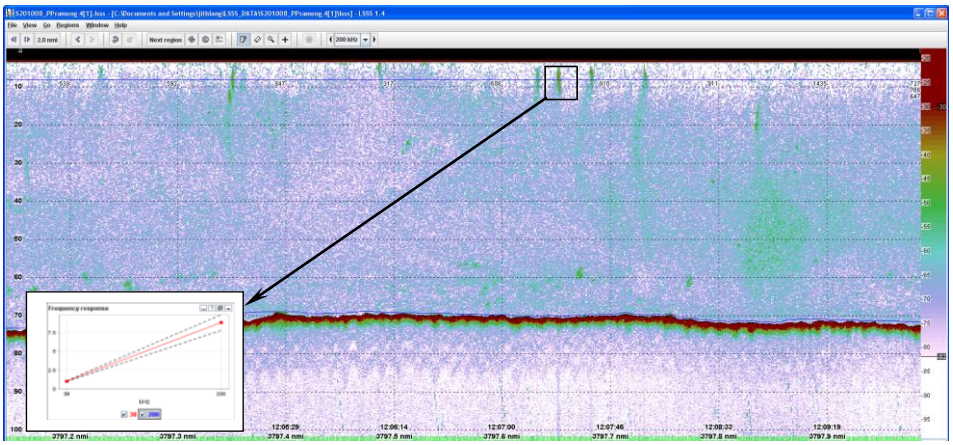


Figure 3.15 *Echogram picture of comparable zooplankton layer at 40-60 m depth in August at day between 200 kHz (a) and 38 kHz (b), The scale is the same as in the previous echogram, but showing about 1.5 nmi of the transect.*

Third echogram (Fig 3.16) is from a night survey at transect line 1, August survey, showing strange schools of zooplankton like aggregations reaching from the surface down to 20 and even 60 meters depth close to the pinnacle. The school formations were stronger at

surface and weaker down in the water column. The backscattering was much stronger at 200 kHz than at 38 kHz, where these targets were not clearly visible at all (Figure 3.16).

a)



b)

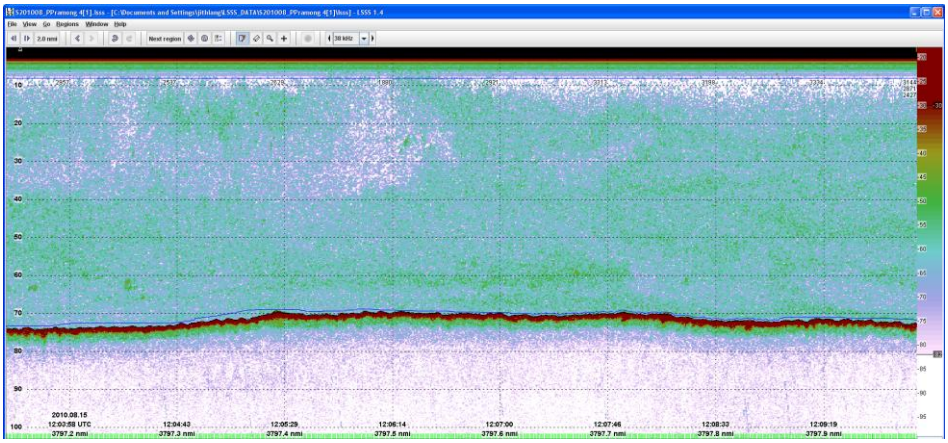
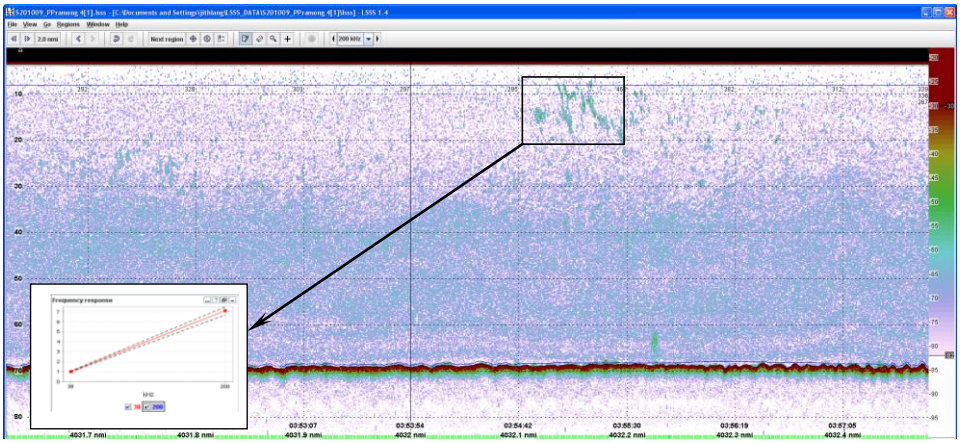


Figure 3.16 *Echogram picture of zooplankton groups recored in August between 200 kHz (a) and 38 kHz (b) at nighttime. Horizontal distance shown is about 1 nmi.*

Fourth echogram is from the September survey, which found some found dense patches of zooplankton-like targets at 10-30 depth on the beginning of the 3th cruise track during day time (Figure 3.17). They also showed clearly up only on the 200 kHz echogram, with a strong positive frequency response, r (f) = 7, but not visible at 38 kHz.

a)



b)

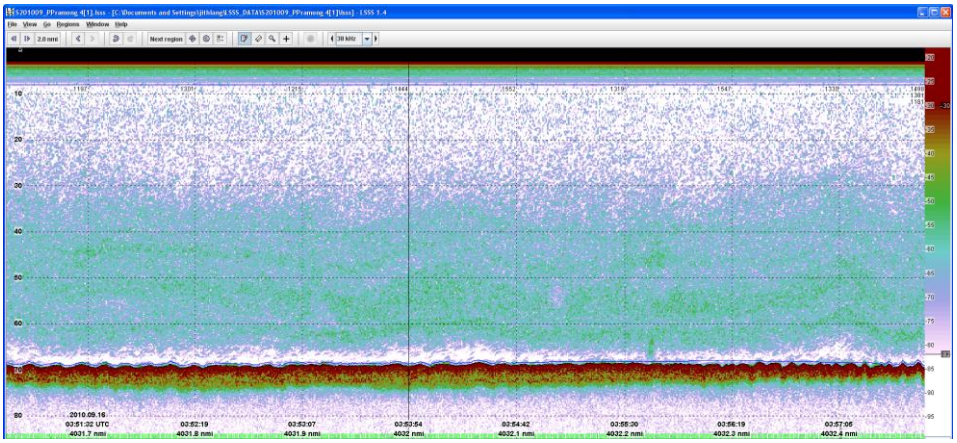
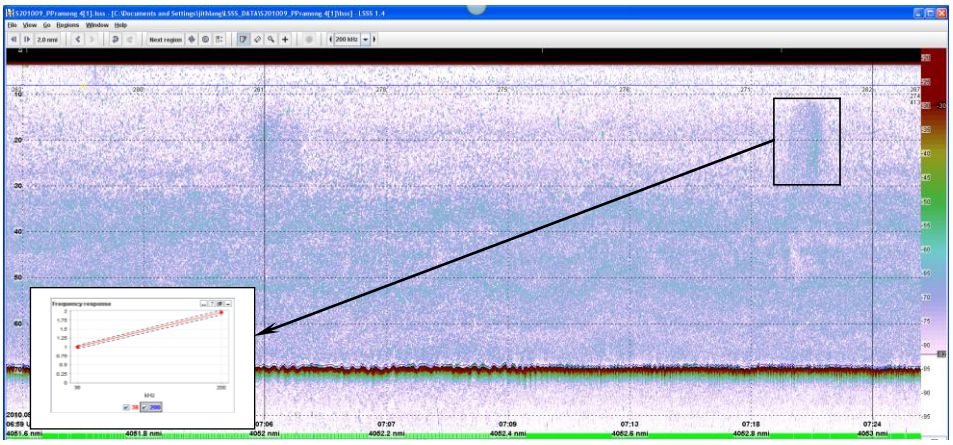


Figure 3.17 *Echogram picture of dense zooplankton-like patches recorded at 10-30 m depth in September, only visible on 200 kHz (a) at daytime. 38 kHz (b) is shown below. Horizontal distance shown is about 0.9 nmi.*

The fifth echogram is from on the 3th transect line, September survey showing 2 large aggregations of zooplankton-like targets at 10-30 m depth around 1.5 nmi from pinnacle. The frequency response was about 2 times stronger at 200 kHz than at 38 kHz (Figure 3.18).

a)



b)

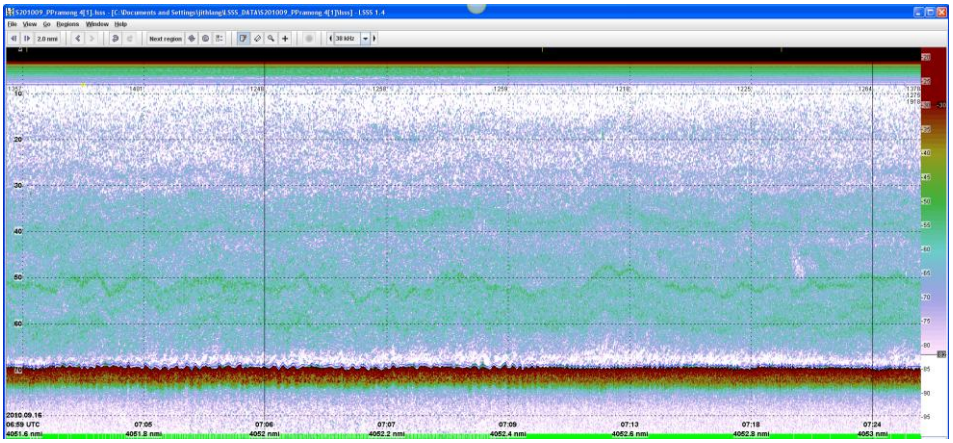


Figure 3.18 *Echogram picture of two zooplankton aggregations at 10-30 m depth in September at 200 kHz (a) and 38 kHz (b) at day time. Horizontal distance is about 1.5 nmi.*

3.3 Abundance Estimation

3.3.1 Copepod abundance estimation

The abundance of echoes assumed to be zooplankton, or copepods is based on the target strength of copepods at 200 kHz. The cube root of the mean cubic prosome length of the copepods was 1.11 mm for all areas. From data on four transects crossing the seamount, a separation was made between the area 0.5 nmi closest to the pinnacle and the area outside of the pinnacle.

The acoustically measured abundance of zooplankton (copepods) at the area outside the pinnacle area was higher than at the pinnacle area throughout study period. The acoustic abundance of copepods was higher at night time for both areas, estimated to be as high as 23.94 to 67.65 kg/m^2 at the pinnacle with a mean abundance 44.23±22.02 kg/m^2. In the area outside the pinnacle, the density ranged from 21.49-76.09 kg/m^2 with a mean abundance of 54.50±19.60 kg/m^2. The highest zooplankton (copepod) abundance was found in August

during nighttime in both areas (Table 3.3). From the density estimates, it was clear that the echoes scrutinized as zooplankton could not have been zooplankton, but that the main smoke-like targets and layers must have been gas bearing phytoplankton with quite high backscattering at both frequencies. Densities of up to one kilo of copepods per square meter surface area are only seldom seen in exceptionally productive areas, like in the Norwegian Sea. The conversion made here from acoustic backscatter to density suggests densities of up to 60 to 70 kg/m^2.

Table 3.3 *Estimated copepod abundance (kg/m^2) at pinnacle and outside of the pinnacle area with 200 kHz during day and night between August-October 2010.*

Area	August		September		October	
	day	night	day	night	day	night
Pinnacle	26.07	67.65	17.25	23.94	12.90	41.11
Outside	31.29	76.09	21.49	37.83	26.20	49.57

3.3.2 Fish abundance estimation

Yellow-tail round scad (*Decapterus maruadsi*) and Indian Mackerel (*Rastrelliger kanagurta*) were the common fish that found at the pinnacle area. The mean length of both species was 19 cm, which were used for calculating mean target strength of the fish on the pinnacle. Based on calculation of abundance of fish. From 38 kHz, the mean density from all four track cruise about 0.1 nmi around pinnacle was highest value in October at day time with 293004 #/nmi^2 and lowest density at night 39546 #/nmi^2. Estimated abundance of fish around area 0.0314 nmi^2 at pinnacle. The total fish abundance was calculated to vary from 4 to 29 tons, with a mean value of about 18 tons ± 9.90 tons (Figure 3.19).

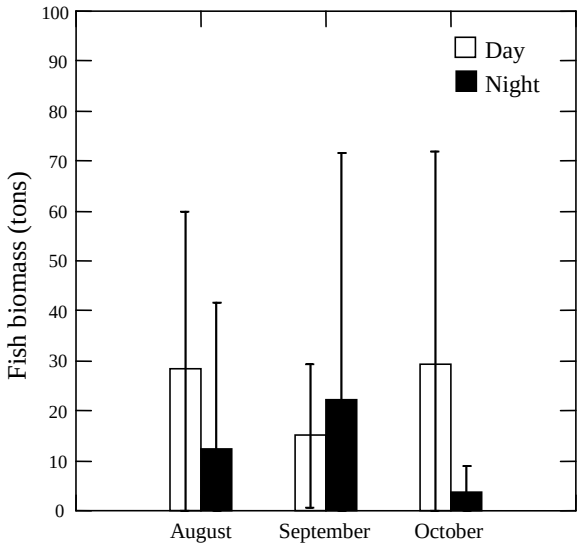


Figure 3.19 *Fish biomass (tons) at 0.0314 nmi^2 of pinnacle estimated from the 38 kHz data during day and night between August-October 2010. Standard deviation is shown.*

3.4 Vertical distribution and biological sampling

Biological sampling was conducted at Sampling Site 1 and 2 during day and night in August to October. Sampling Site 1 was in the area close to the seamount, at 0.5 nmi distance, and Site 2 was further away, about 1.5 nautical miles from the seamount. Some of the planned sampling periods could not be conducted due to storm with strong wind during the survey period. These are the August, night-time, Site 2 sampling and the October night-time, Site 1 sampling.

3.4.1 Density and vertical distribution of plankton with acoustic sampling

The vertical distribution of plankton-like targets for Sampling Site 1 varied at both frequencies. At 38 kHz, the density of plankton varied for all sampling periods (Figure 3.20). There was high density in August ranging from 25-715 m^2/nmi^2 at day and 130-520 m^2/nmi^2 at night. The plankton-like targets was abundant at the 30-40 m depth at day while night time was higher density in the 30-50 m depth intervals. The plankton density decreased in September, varying from 30-235 m^2/nmi^2 and 80-265 m^2/nmi^2 in day and night time, respectively. The vertical distribution was similar both day and night. In October at daytime, the mean backscattering was between 40-230 m^2/nmi^2. Low densities were found in the 20 to 40 meter depth intervals, while the highest density was found in the deepest depth intervals. A similar picture vertically, but with lower backscattering, was also seen in the 200 kHz system (Figure 3.21).

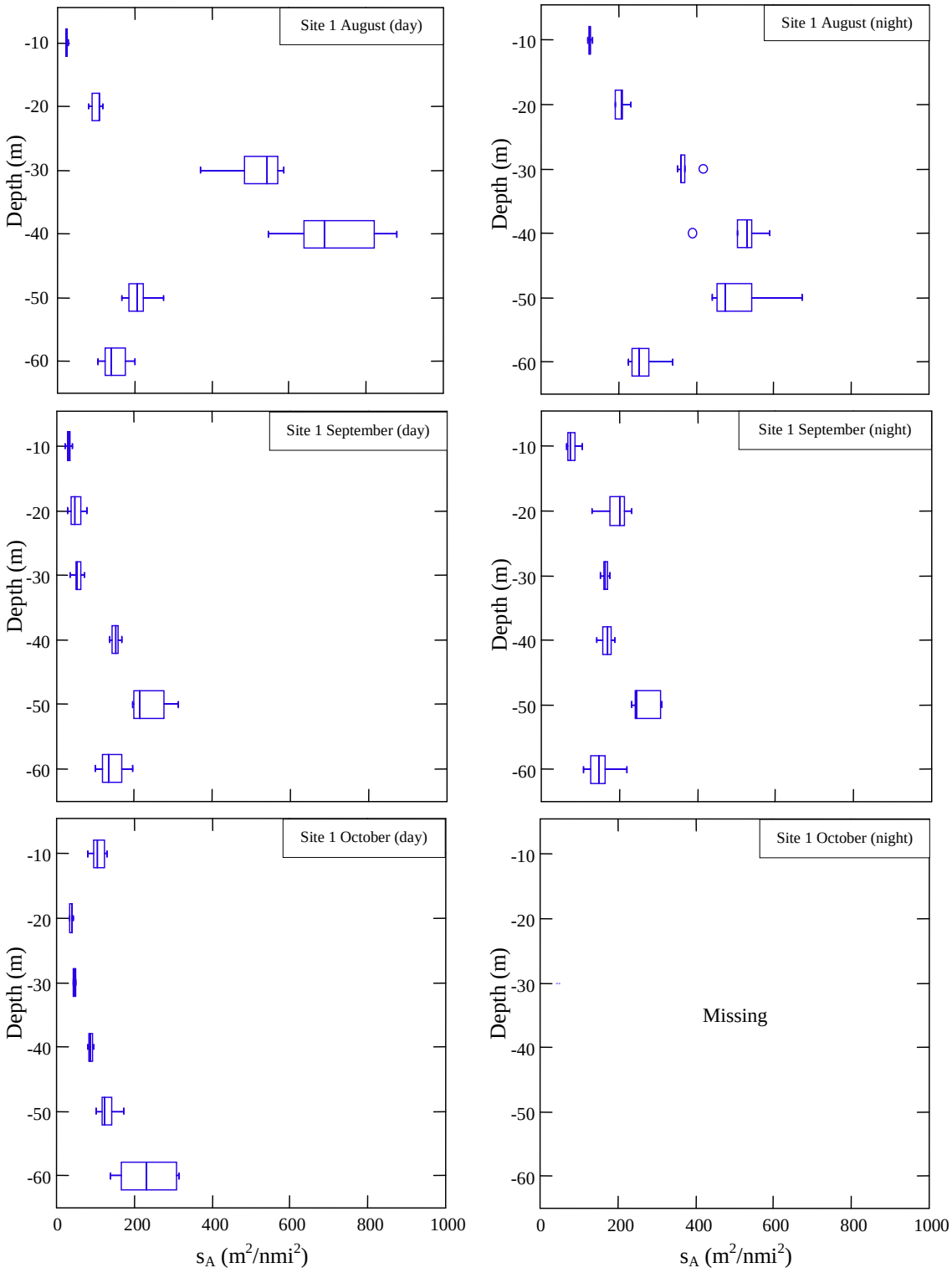


Figure 3.20 *Boxplot of mean acoustic backscattering (s_A), of plankton at Sampling Site 1 at 38 kHz during day and night between August-October 2011.*

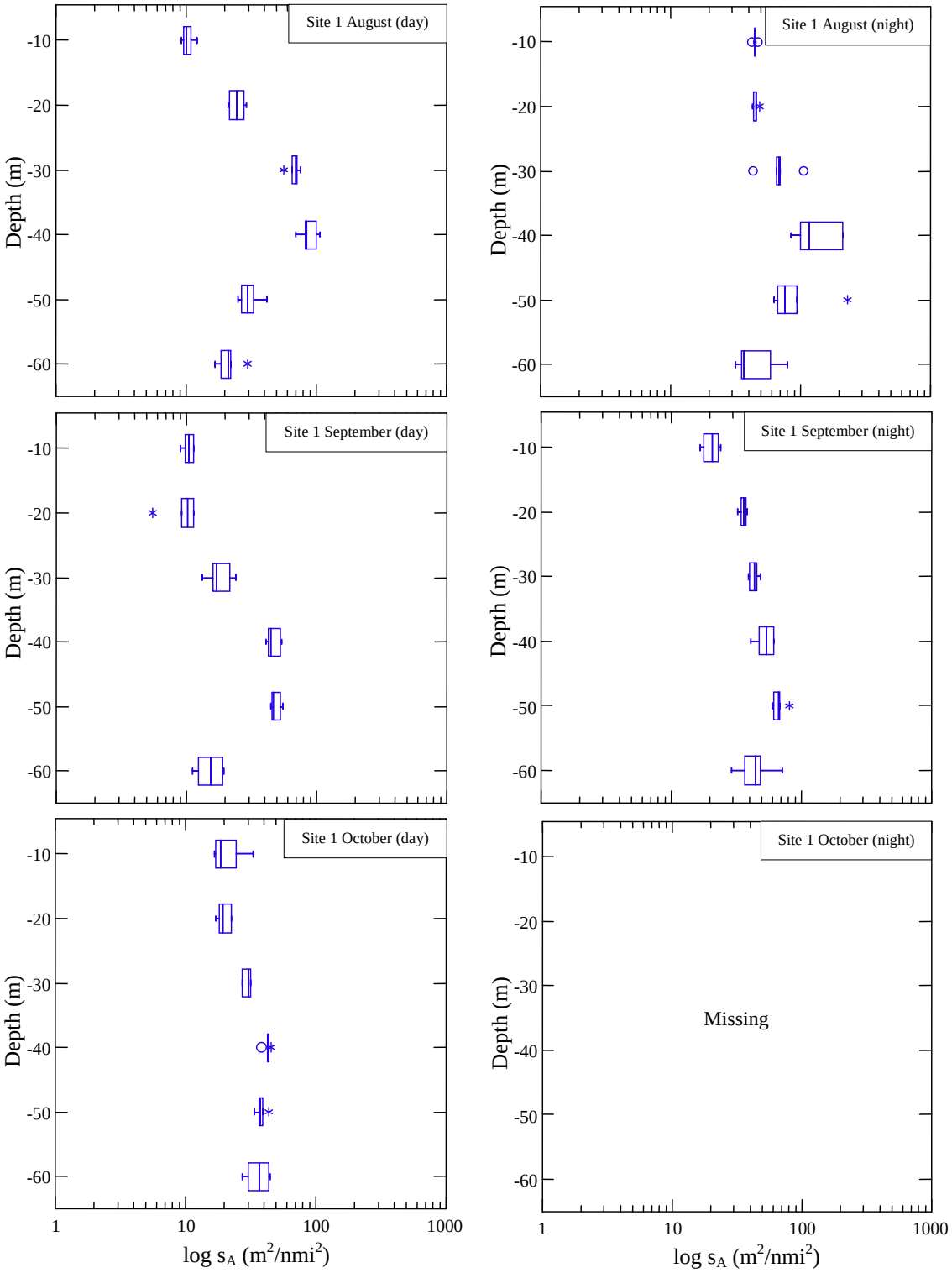


Figure 3.21 *Boxplot of acoustic backscattering (s_A), of plankton at Sampling Site 1 at 200 kHz during day and night between August-October 2011. Note: x-axis: log n m^2/nmi^2.*

The vertical distribution of zooplankton-like targets at Site 2 changed between sampling periods. Based on the 38 kHz frequency (Figure 3.22), plankton density was high at 30 m depth in August at daytime. The density decreased in September but with similar distributions both at day and night, with highest density at about 50 m depth. The mean backscattering varied from 13-280 m^2/nmi^2 at day and 50-310 m^2/nmi^2 at night. In October, however, the highest density was found at 60 m depth at day, ranging from 60 to 240 m^2/nmi^2. At night, the density was highest at 50 m depth, varying from 70-640 m^2/nmi^2. For the 200 kHz, a similar picture is seen, with highest density at 20-40 depth in August at daytime but with lower backscattering compared to the 38 kHz, 10-65 m^2/nmi^2. In September, the highest density was located at 30-50 m depth at daytime and at 50-60 m depth at night, with backscattering ranging from 5-33 m^2/nmi^2 and 19-66 m^2/nmi^2, respectively. In the October survey the vertical distribution was similar day and night with the highest density in the 50–60 m layer (Figure 3.23).

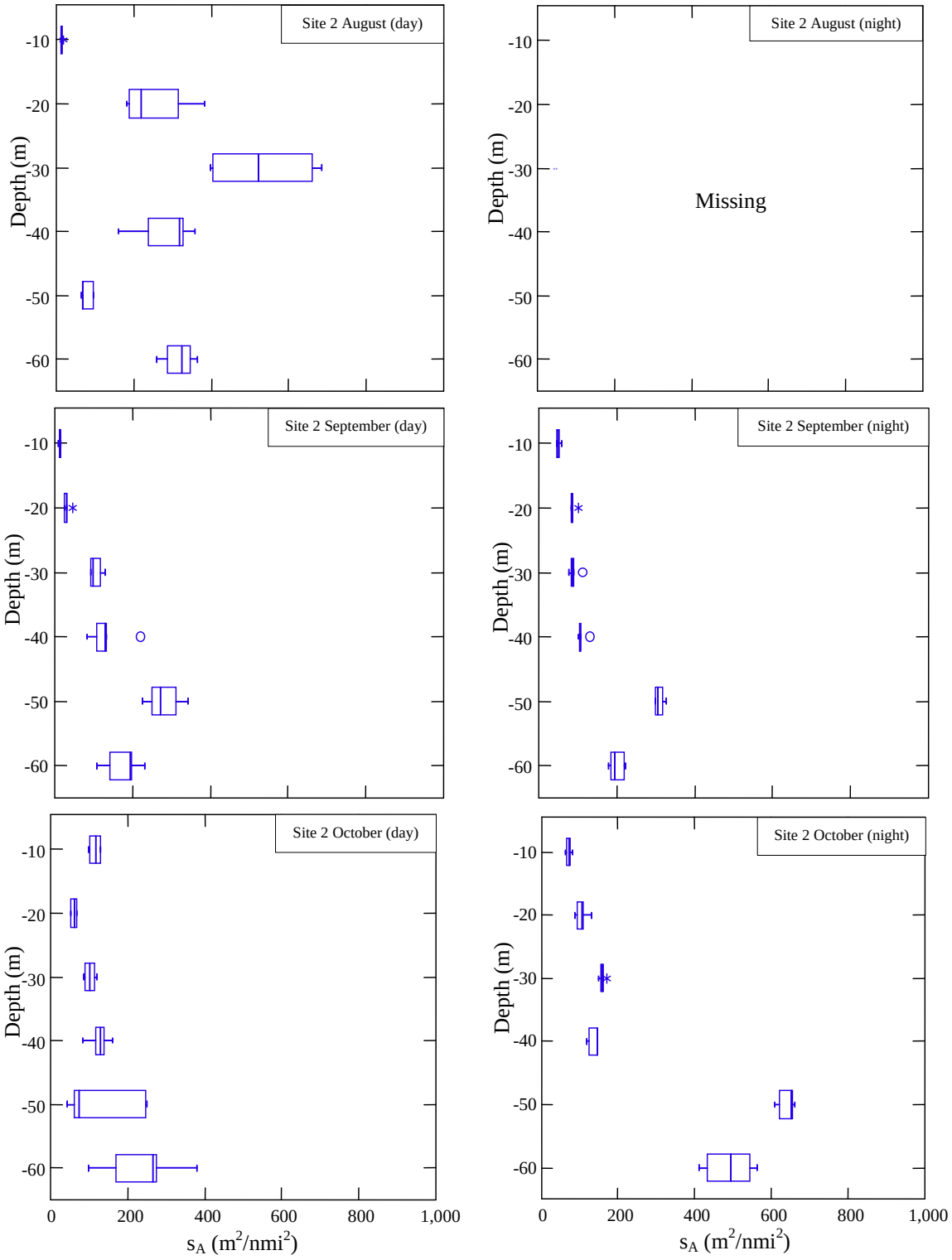


Figure 3.22 *Boxplot of mean acoustic backscattering, (s_A), plankton-like targets at Sampling Site 2 at 38 kHz during day and night between August-October 2011.*

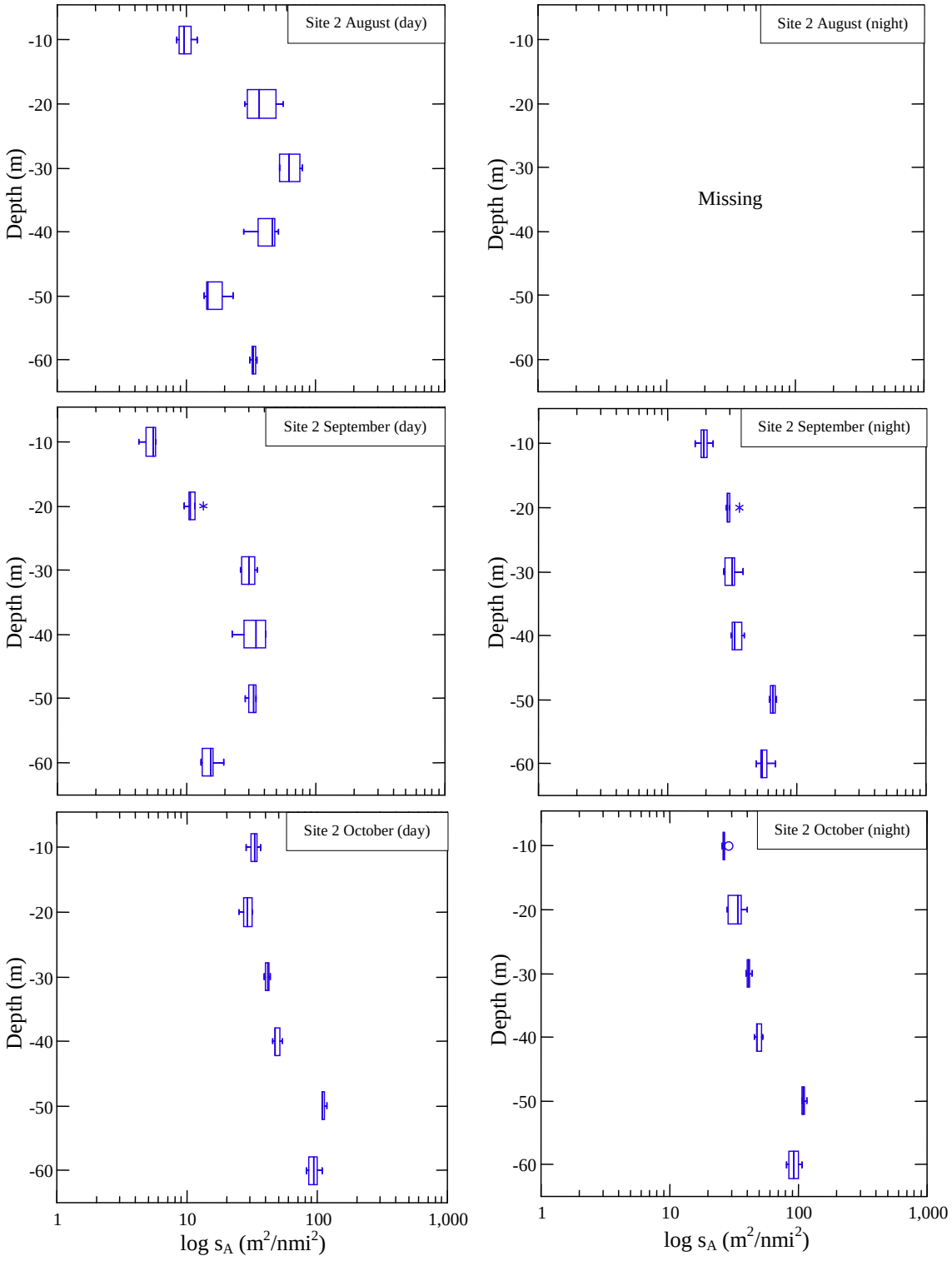


Figure 3.23 *Boxplot of mean acoustic backscattering, (s_A), plankton-like targets at Sampling Site 2 at 200 kHz during day and night between August-October 2011. Note: x-axis: log n m^2/nmi^2.*

The table 3.4 shows that the overall density of plankton was not different between Sampling Site 1 and 2 as between month or between day and night time ($p>0.05$) for any of the frequencies. Whereas, the density between day and night shows a difference at 38 kHz ($p<0.05$) and the difference is also significant at 200 kHz ($p<0.001$). However, there are are also a deifference between depth for all sampling period at frequencies ($p<0.05$) except for at 200 kHz during day time ($p>0.05$).

Table 3.4 *p-value for comparisons of zooplankton density sampled with different methods, between sampling sites, month, time and depth.*

Method/gears	Site 1-Site 2	3 month		10-60 m depths		Time (day-night)
		day	night	day	night	
38 kHz frequency	> 0.05	> 0.05	> 0.05	0.010*	0.020*	0.011*
200 kHz frequency	> 0.05	> 0.05	> 0.05	> 0.05	0.013*	0.001**
Bongo net	> 0.05	0.048*	> 0.05	0.026*	0.021*	> 0.05
Van Dorn water sampler	> 0.05	> 0.05	> 0.05	0.044*	> 0.05	> 0.05
Biomass	> 0.05	> 0.05	0.001**	0.018*	> 0.05	> 0.05

3.4.2 Abundance and vertical distribution of zooplankton sampled with Bongo net

3.4.2.1 Abundance and distribution of zooplankton

Zooplankton samples were collected by the Bongo net for studying mesozooplankton and fish larvae. The abundance of zooplankton from Bongo nets shows no difference between Sampling Site 1 and 2. Also, there are no difference between day and night sampling ($p>0.05$). The abundance comparison between months are different during day ($p<0.05$) while at night, there is no difference. The vertical distribution, from 10 to 60 m depths reveals difference between day and night (Table 3.4).

The zooplankton abundance at Sampling Site 1 diverged throughout the study period according to Figure 3.24. The abundances were higher at the depth intervals 10-20 m and 60 m depth for all study periods. In August, a higher density was found at 10-20 m and 60 m depths both of day and nighttime. The abundance at day time (83-402 individuals/m^3) was higher than during night time (70-233 individuals/m^3). Also, it was similar in September, when the abundance sampled at daytime was higher than at night, varying from 92-471 individuals/m^3 to 152-303 individuals/m^3, repectively. The abundance was high at 20 m and 60 m depth intervals both during day and night, with the highest abundance at 60 depth during

daytime. In September, the zooplankton abundance decreased to 46-214 individuals/m^3 with the highest abundance at the deepest depth. There was generally higher abundance at the deeper depth as illustrated by Figure 3.24.

Furthermore, at Site 2, it appears evident that there must be vertical migration, from the distribution patterns seen in Figure 3.25. In August, the zooplankton was abundant at surface and bottom depth while the abundance at middle depth was low, varying between 88 to 346 individuals/m^3. The result from September represented an altered distribution pattern. The abundance was dense at bottom depth (50-60 m depth) with 337-564 individuals/m^3 during daytime. By contrast, at night time the abundance was very high at surface depth (10-20 m depth) ranging from 240-622 individuals/m^3, while the density close to the bottom was low. Also, at daytime in October, the zooplankton was slightly higher close to the bottom with 265 individuals/m^3, but evenly distributed in the rest of the water column, varying from 119 to 190 individuals/m^3.

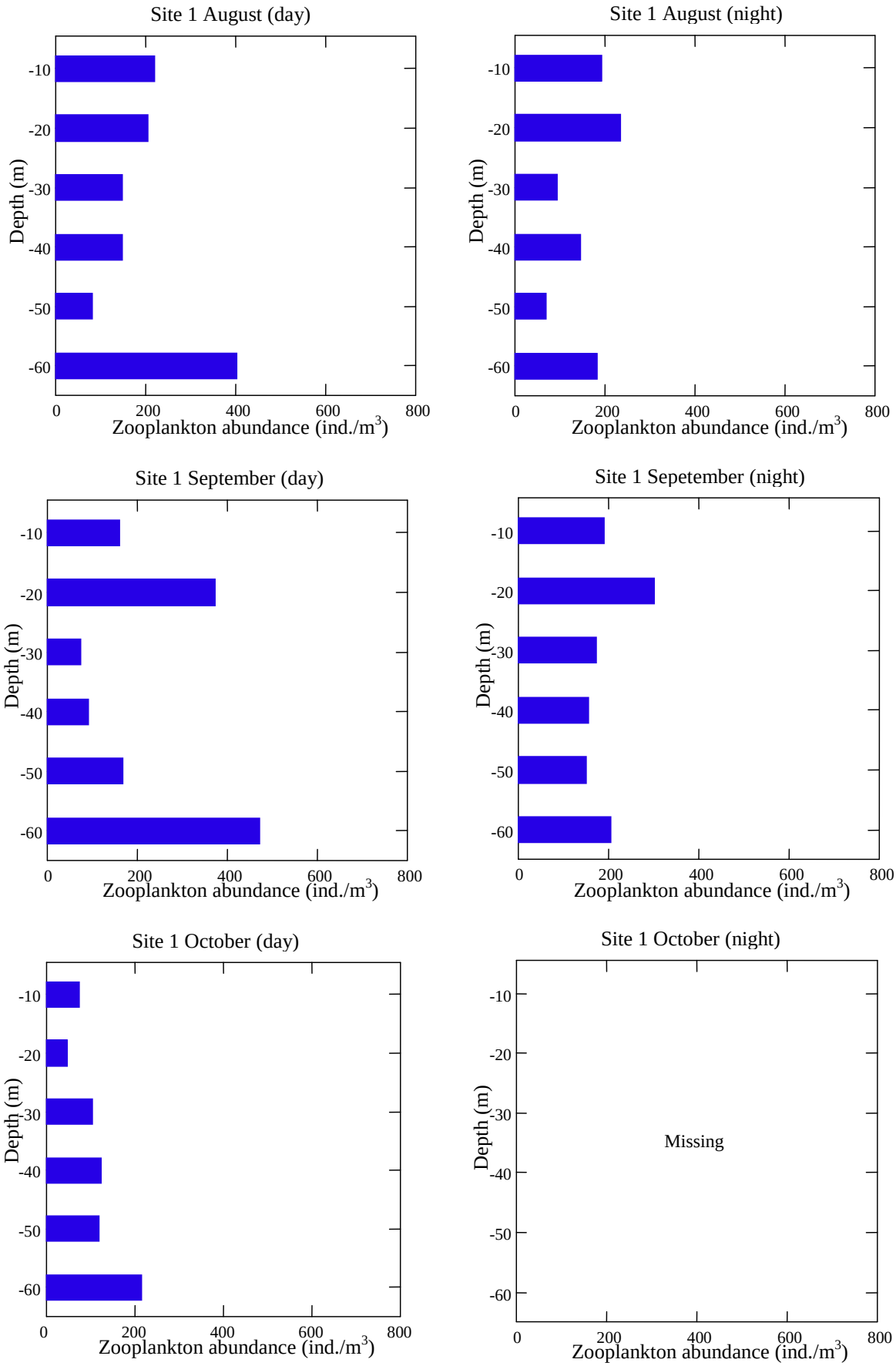


Figure 3.24 *Zooplankton density (individuals/m^3) collected by the Bongo net at Site 1 during day and night between August-October 2011.*

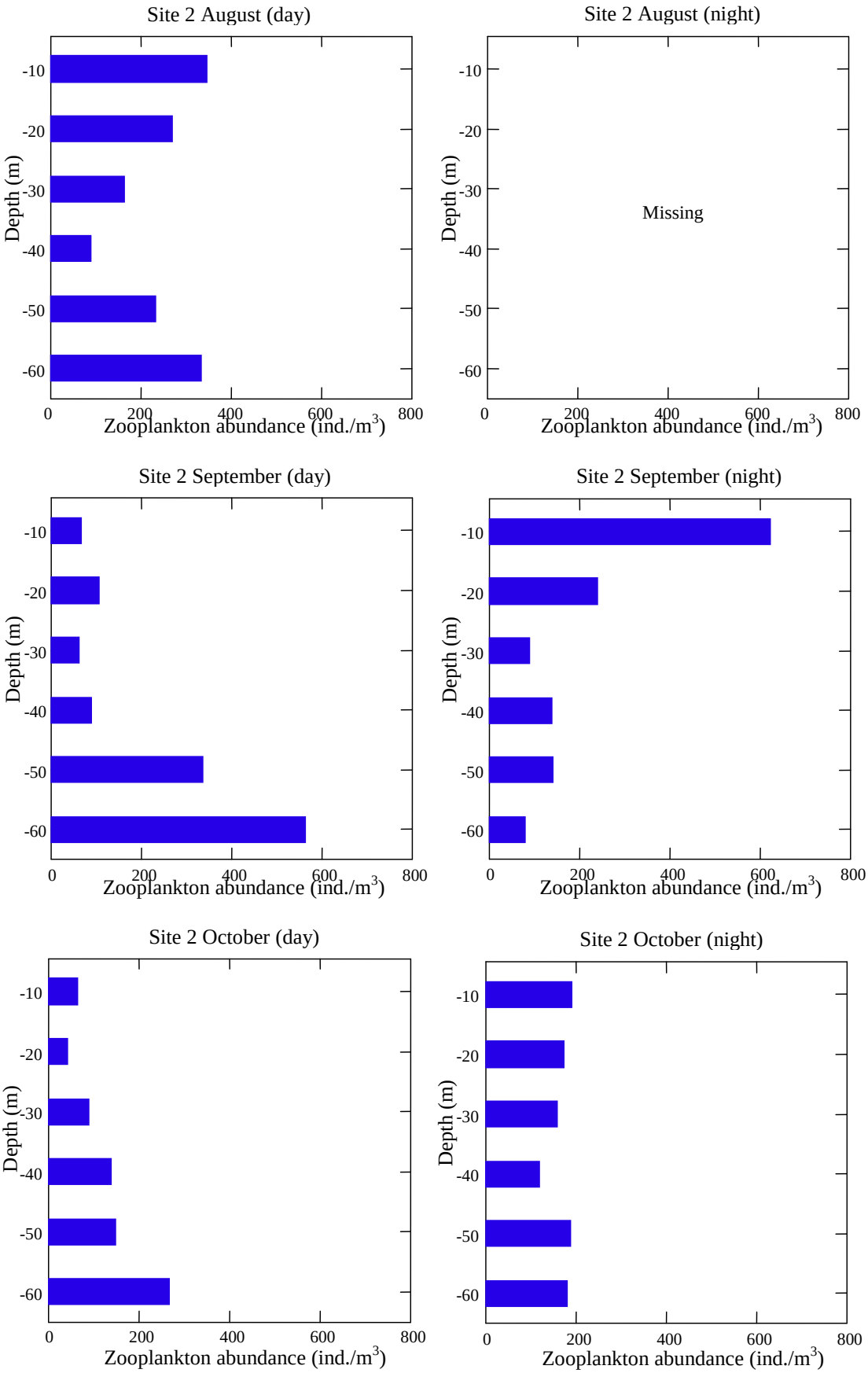


Figure 3.25 *Zooplankton density (individuals/m^3) collected by the Bongo net at Site 2 during day and night between August-October 2011.*

3.4.2.2 Species composition of zooplankton

The samples were collected from 10-60 m depth intervals at 2 sampling sites during day and night time in three months (August, September and October). Only the sample at the depth with highest abundance from both of sampling sites, for each survey, were selected for studying the species composition of zooplankton.

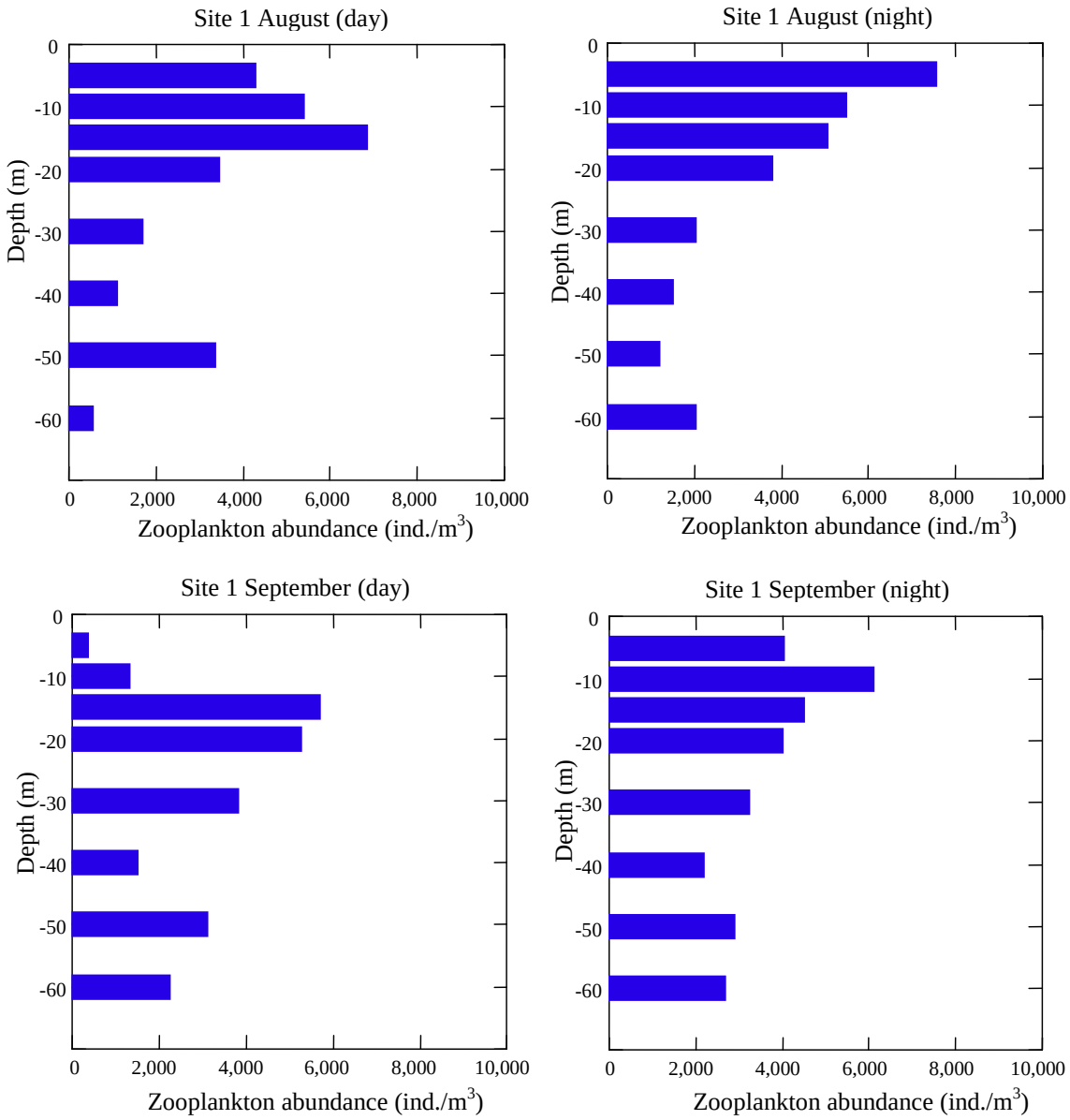
Zooplankton community in both of sampling sites consisted of 44 genera and 32 taxa. Copepods were the most diverse group containing the highest number of species with 27 genera. Also, Copepoda were the most abundant taxon accounting for 70% of total zooplankton densities both of sampling sites. Within the copepod communities, the abundance of calanoid copepods was 77% of total copepods followed by poecilostomatoids (18%), cyclopoid (4%) and harpacticoid (1%). The dominant species included *Euchaeta* spp. with 24% of total copepod followed by *Oncea* sp. (13%) *Canthocalanus* sp. (10%) *Paracalanus* sp. (6%) *Acartia* spp. (6%) and *Corycaeus* spp. (4%). In addition, Ostracoda ranked the second in abundance after copepods made up for 7% of total zooplankton density. Other common taxa were Foraminifera (5%) Malacostraca with Mysidacea, Amphipoda, Euphausiacea, Larval Decapoda around 4% and Chaetognatha (3%) while fish larvae was only 0.5% of total zooplankton as indicated in the tables shown Appendix 1 and 2.

3.4.3 Abundance and vertical distribution of zooplankton sampled with Van Dorn water sampler

Microzooplankton was also studied with Van Dorn water sampler in the study area. The abundance of zooplankton only shows difference between 10-60 m depth layers during daytime ($p<0.05$). No difference in the vertical was revealed in the other tests ($p>0.05$), (Table 3.4). At Sampling Site 1, the microzooplankton was mostly abundant at surface depth (5-30 m) all of day and night in August (1700-7750 individuals/m^3) and September (1300-6100 individuals/m^3) while the abundance decreased in October showning similar distribution at all depths ranging from 1800-3100 individuals/m^3 (Figure 3.26)

Moreover, the zooplankton abundance at Sampling Site 2 was similar in distribution pattern as for Site 1. There was high abundance at surface depths (5-30 m) in August ranging from 4050-9200 individuals/m^3 and 2100-4650 individuals/m^3 in September whereas there a more even depth distribution in October varying from 30-2550 individuals/m^3 at day and 800-2700 individuals/m^3 during nighttime (Figure 3.27).

Copepoda were the most abundant microzooplankton group sampled by the Van Dorn water sampler, representing the highest percentage of total zooplankton with 79% followed by Urochordata (Tunicata) with 8% Chaetognatha (4%) Foraminifera (2%) and Cnidaria (2%) as shown in Appendix 3.



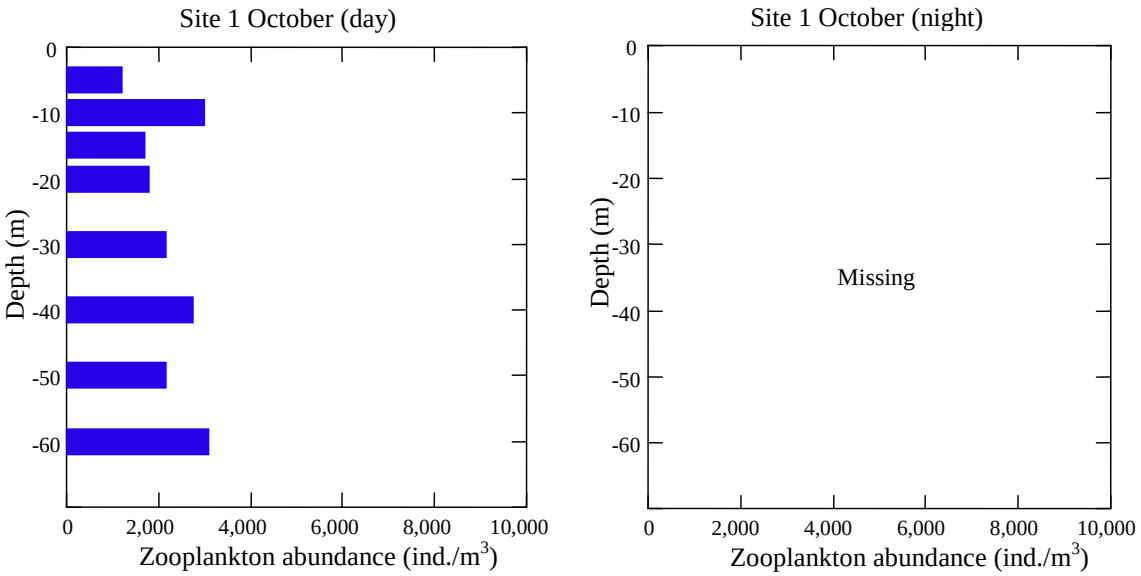
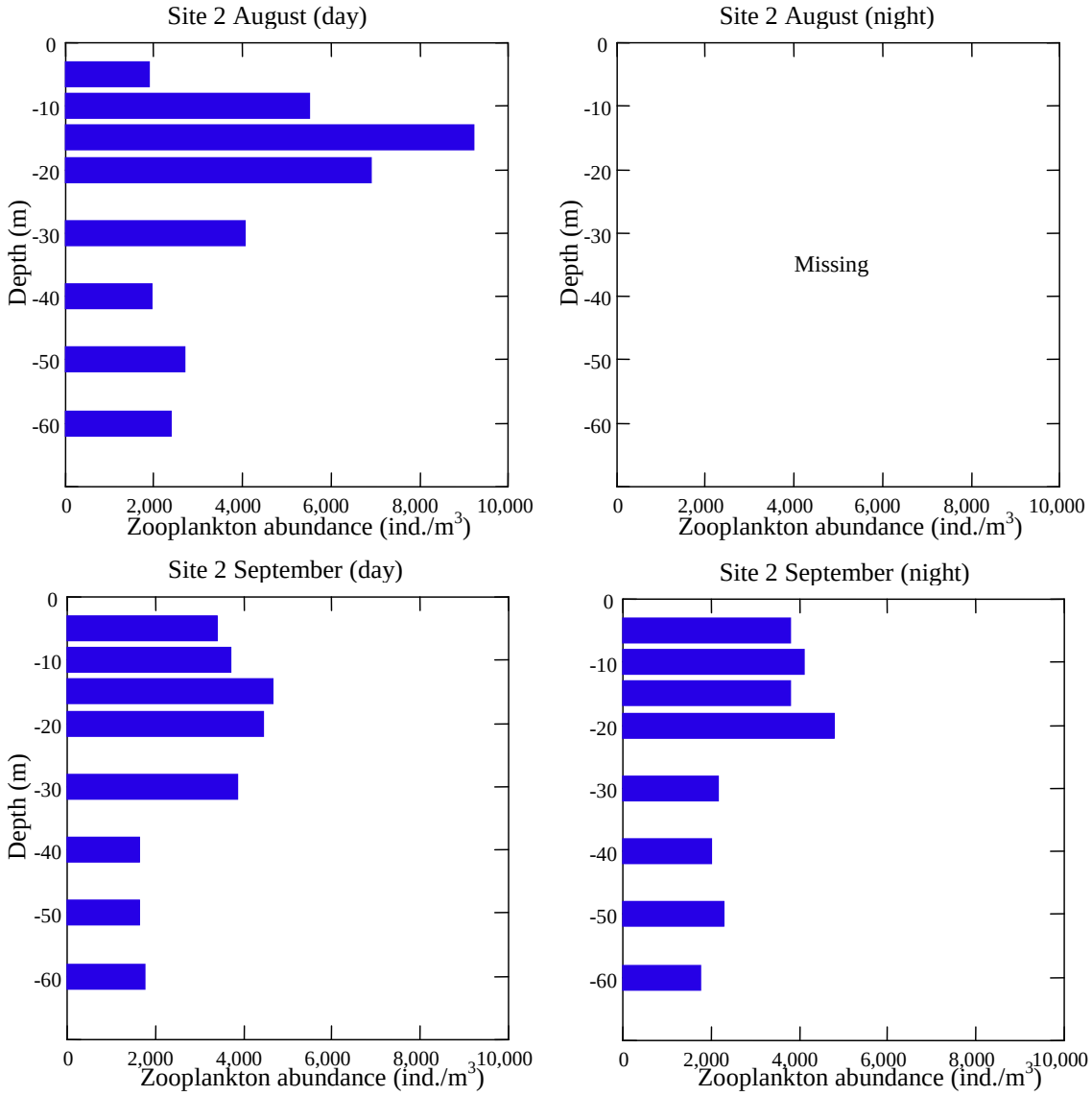


Figure 3.26 *Zooplankton abundance (individuals/m^3) collected by the Van Dorn water sampler at Site 1 during day and night between August-October 2011.*



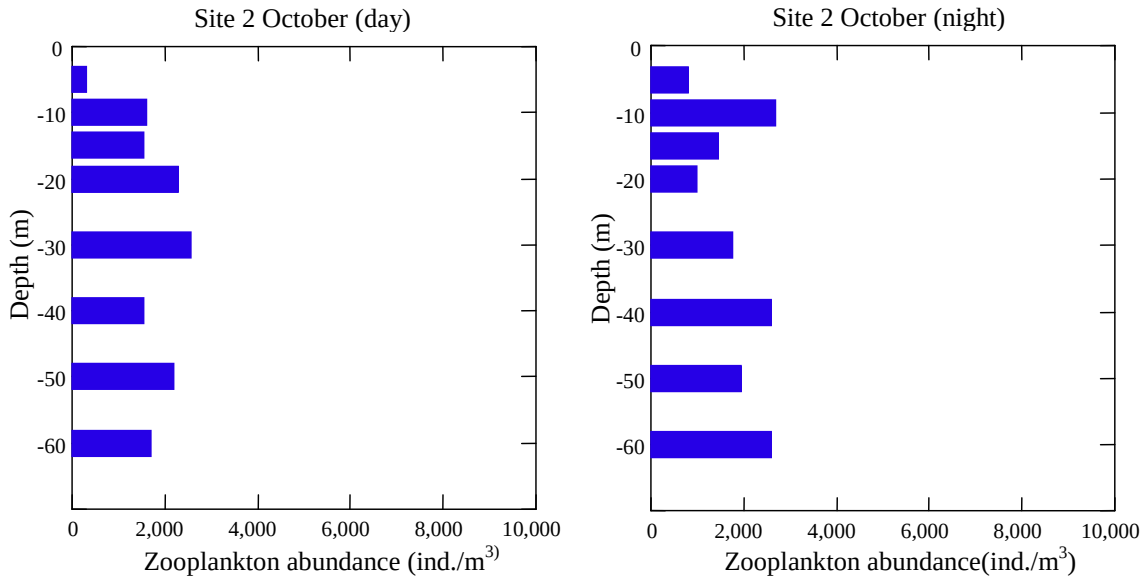


Figure 3.27 *Zooplankton abundance (individuals/m^3) collected by the Van Dorn water sampler at Site 2 during day and night between August-October 2011.*

3.4.4 Zooplankton dry weight biomass

The zooplankton samples from Bongo net collection were also used for analyses of dry weight biomass. The biomass of zooplankton was different between depths at day time ($p<0.05$). The difference in biomass was also significant between month at night time ($p<0.001$) (Table 3.4). The zooplankton biomass at Sampling Site 1 varied over this study period (Figure 3.28). Similar values all depth intervals both during day, ranging from 0.0020-0.0062 mg/m^3 and 0.0022-0.0043 mg/m^3 at night were recorded in August. The biomass increased in September. The highest biomass at daytime was found at 60 m depths with 0.0184 mg/m^3 while there was similar biomass at all depth intervals, between 0.0083 to 0.0104 mg/m^3 at night. In October, the highest biomass was found in 60 m depth.

Additionally, the biomass at Sampling Site 2 also changed throughout sampling period as indicated in Figure 3.29. There was steady biomass between 0.0025-0.0047 mg/m^3 for all depth in August. The biomass in September was higher at 50-60 m depth (0.0158-0.0170 mg/m^3 at daytime and 0.0082-0.0132 mg/m^{3}at night). In October, there was an increasing biomass with depth to 0.0131 mg/m^3 in the deepest layer, while at night, the biomass was high (0.0093-0.0120 mg/m^3), but more evenly spread in the water column.

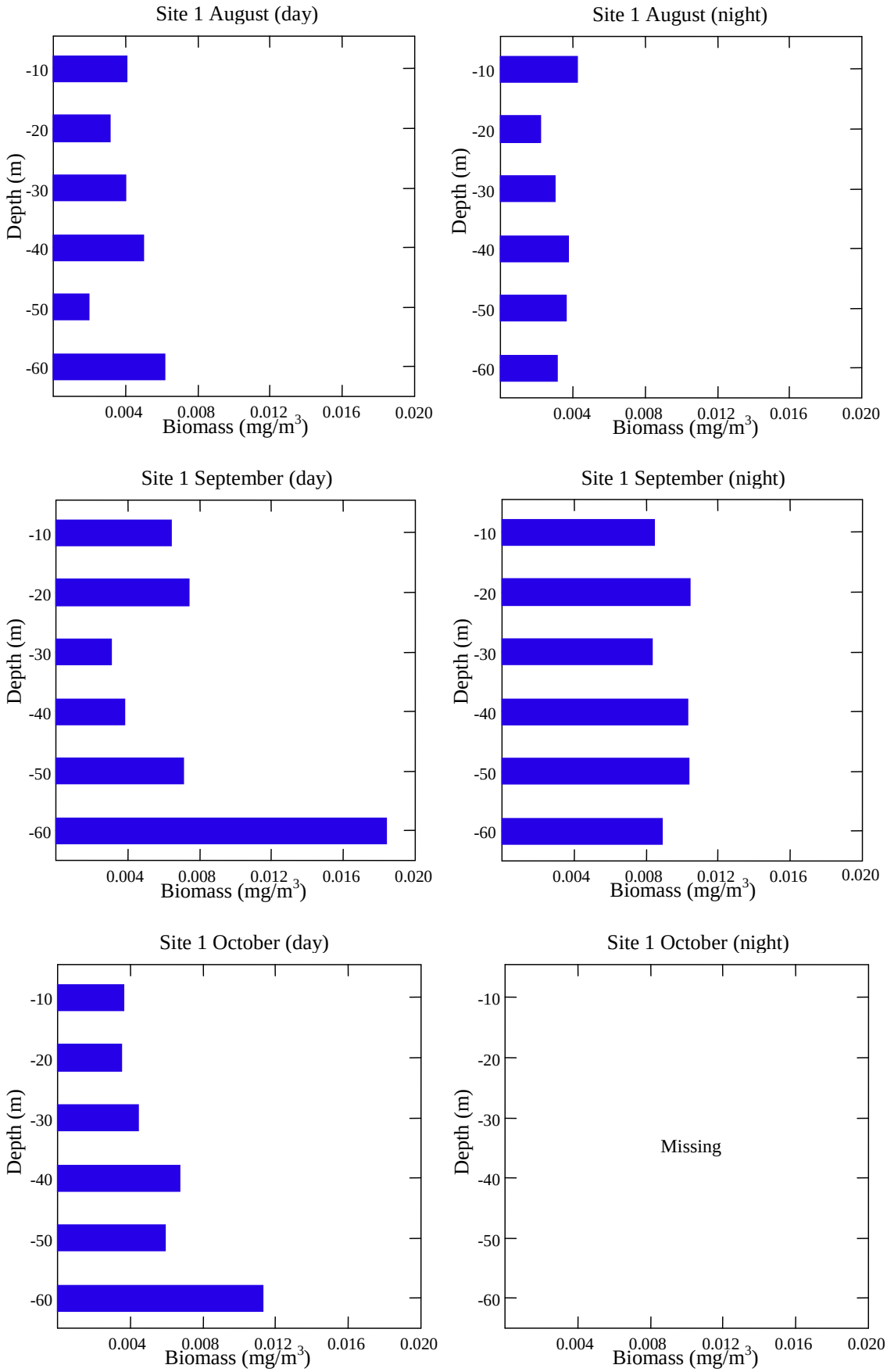


Figure 3.28 *Zooplankton biomass (mg/m^3) collected by the Bongo net at Site 1 during day and night between August-October 2011.*

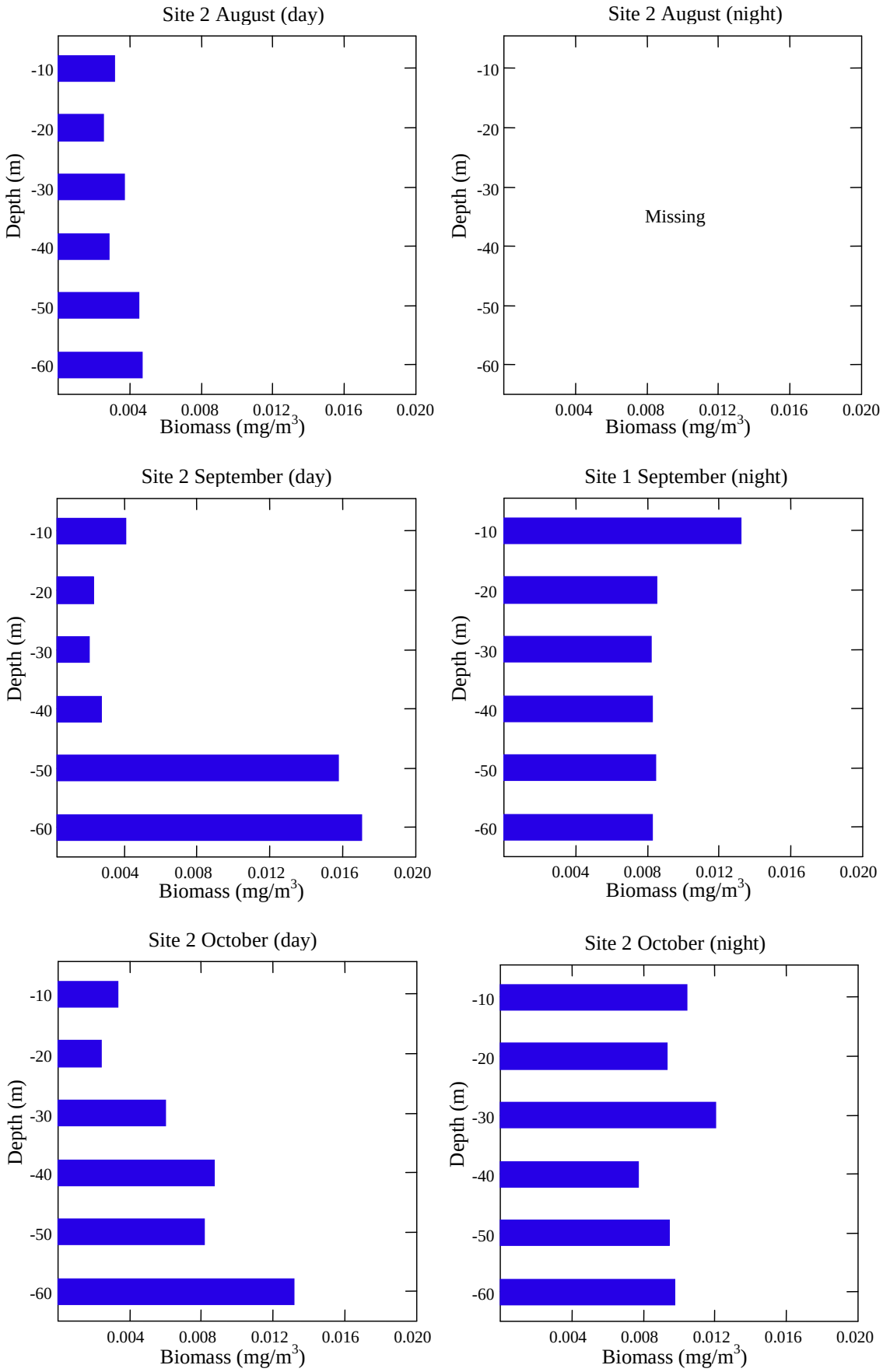


Figure 3.29 *Zooplankton biomass (mg/m^3) collected by the Bongo net at Site 2 during day and night between August-October 2011.*

3.4.5 Comparison of acoustically measured zooplankton abundance and biologically sampled abundance

First, the general echograms revealed similar registrations of zooplankton-like targets on both frequencies, but much stronger on the 38 kHz. This is actually a first indication that this is other objects than zooplankton, since an opposite relationship between the frequencies is expected according to the acoustic modeling. However, when comparing the two frequencies, a strong correlation between the two are seen (r = 0.78) (Figure 3.30), reflecting a fairly constant frequency response of the layers. Apart from the special cases presented in the echograms earlier, the correlation is similar in most depth intervals.

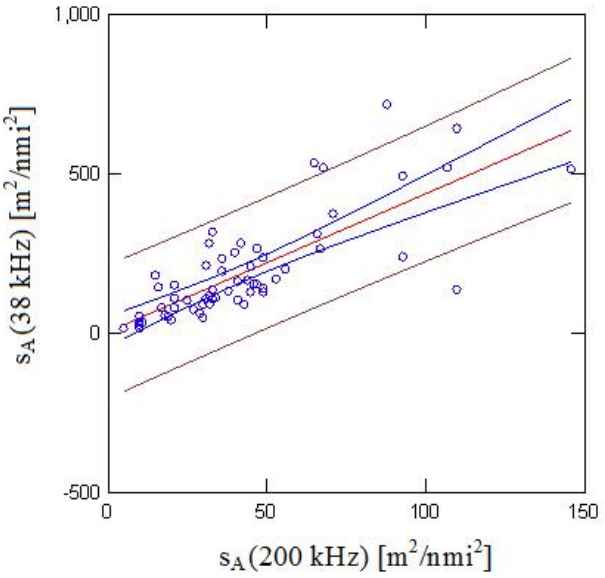


Figure 3.30 *Correlation of acoustic backscattering,(s_A),of zooplankton like layers between 38 kHz and 200 kHz.*

Further, and in the order to prove that the abundance of copepods must have been grossly overestimated by the acoustic measurements, the relationship between the density measured with acoustics, 38 and 200 kHz, can be compared with the biological samples with Bongo net and Van Dorn water sampler. Linear regressions between acoustic backscattering and biological density in the two sampling devices used are shown in Figure 3.31. The comparisons all show very low correlation between acoustically measured density and biologically measured density (Figure 3.31 a, b, c and d). The relation between Bongo net abundance estimation and 38 kHz acoustical has a correlation of r = 0.06 increasing to r = 0.23 when compared with the backscattering at 200 kHz. Similarly, the relationship

between Van Dorn water sampler abundance and measured backscattering at with 38 and 200 kHz was slightly higher r = 0.36, but negative. As a conclusion, there is little evidence for a correlation between the acoustically measured zooplankton abundance and the density measured by biological sampling. Also, since the abundance of plankton from the acoustic systems was much too high, and therefore could not have reflected the true density, this is probably better described by the biological sampling. The main reasons for this will be explained in the discussion.

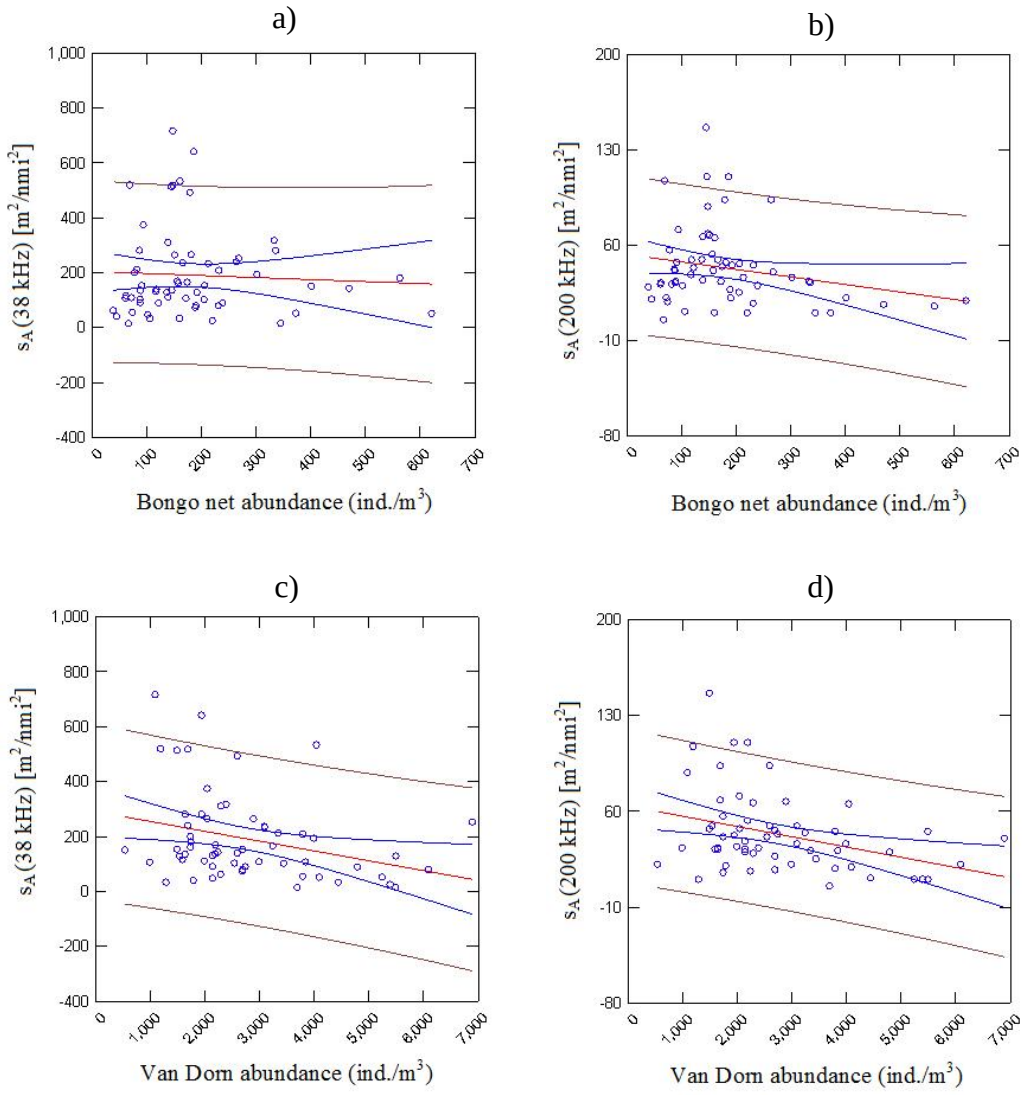


Figure 3.31 *Correlation between acoustic (38 kHz and 200 kHz; m^2/nmi^2) and biological (Bongo net and Van Dorn water sampler; individuals/m^3) abundance estimation.*

Further, the abundance of zooplankton between the two applied biological sampling devices (Bongo net and Van Dorn water sampler) was compared. Even here, there is an unexpected low correlation (r = 0.20) (Figure 3.32) between the densities measured. The results seem to indicate that the different net mesh sizes in the two gears must be responsible for part of the difference. The density in the Van Dorn water sampler is about 10 times higher (ind./m^3) than in the Bongo net, and the 10 fold increase in density for the Bongo net, 30–900 ind/m^3, is not followed by a similar increase in the Van Dorn density. Different size of zooplankton was also sampled with the two gears. The large sized animals were better collected with Bongo net and the smaller size was more efficiently sampled with Van Dorn water sampler. Also, some large zooplankton such as mysidacea, amphipoda, euphausiacea larval of decapoda and fish larvae are avoiding the Van Dorn water sampler since they have stronger swimming capacity, but also because of their low abundance. Therefore, the two gears give quite different zooplankton abundance and species composition. The reasons for this and its implications will be further dealt with in the discussion.

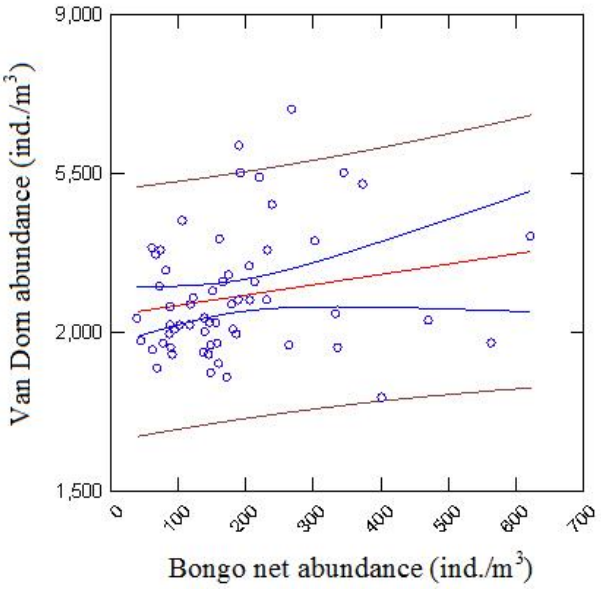


Figure 3.32 *Correlation abundance estimation (individuals/m^3) of biological sampling between Bongo net and Van Dorn water sampler.*

4. Discussion

This study was conducted during the southwest monsoon period in the Andaman Sea, Thailand which has storms, heavy rainfall and strong ocean currents. Also, this is the first study on zooplankton abundance where acoustic sampling tools were tried around a specific seamount in the Andaman Sea. In this study we tried to estimate the abundance of zooplankton around the seamount with the available echo sounder frequencies, 38 and 200 kHz, and biological sampling. The results showed that the acoustic detection and measurements of zooplankton at the selected frequencies might be problematic due to gas filled phytoplankton in the water column and very low zooplankton densities. Also deviating results between the biological sampling gears were observed.

4.1 Environmental at study area

The environmental parameters comprised dissolved oxygen, temperature, salinity and pH value around the seamount, and was quite stable throughout the monsoon period. These are consistent with data from Department of Marine and Coastal Resources (2005), Buranaphatheprat et al. (2010) and Laongmanee et al. (2008) who studied water quality during the non monsoon season offshore in the Andaman Sea. Their data showed similar results as found in this study. It seems like these parameter does not change much over the year. Also, Limpsaichol et al. (1987) investigated the water quality in coastal areas of the southern part of the Andaman Sea. They also reported very similar values for this area except for dissolved oxygen, which was higher in coastal areas than offshore. This might be the environmental parameter in the Andaman Sea which is most steady over wide areas. Salinity was evidently increasing with depth as well as temperature, which slightly decreased with depth. The other parameters were basically constant throughout the water column. Based on my result, the environmental condition sampled during the monsoon season, did not reveal large differences compared to data collected in the non monsoon period (Department of Marine and Coastal Resources, 2005; Laongmanee et al., 2008; Limpsaichol et al., 1987).

Hence, the environment parameters at the seamount were quite similar to the data from another area as reported by the Andaman Sea Fisheries Research and Development Center (personal communication), who studied environmental conditions in the Andaman Sea about 5 nautical miles south west of the seamount between 2005 to 2009 during the non monsoon period. Salinity and pH showed similar values at all depths intervals, while the temperature decreased with depth but with lower temperature close to the bottom than found in this study.

Also, it was evident that dissolved oxygen in the water column decreased with depth over the study period as well as very low values (0.89 mg/l) at 60 m depth. In this study, however, the dissolved oxygen was found to be quite steady with only a slight change throughout the water column. This may have been related to the physical interaction occurring when the sea current flows around and over the seamount, with eddies formed, internal waves and turbulent mixing (Lavelle and Mohn, 2010).

The ocean current during the period flowed cyclically in an east western direction with a net total northward direction in August and September while the total movement is in southwards direction in October with slightly higher current speed. The monsoonal climate dominates in the Andaman Sea during this study showing the southwest or summer monsoon (Khokiattiwong, 1991; Tomczak and Godfrey, 2001). Shankar et al. (2001) studied the monsoon currents in the north Indian Ocean and explained that the summer monsoon current flows eastward during the summer monsoon (May–September). Whereas, the current directions in the northeast monsoon (January-April) along the shore line at Kradan Island, Lanta Island and mainland of Krabi province showed constantly a southwards flow over the entire water column (Khokiattiwong, 1991). The tidal cycles in this study confirmed the change for every 6 hours, similar to the pattern found in Deep Water Ocean Current Measurement in the Andaman Sea during September-November (www.oceandatatech.com, 2001). A seamount in the open sea interact with the sea current and converts to smaller wave length and turbulence including the shedding of ocean eddies that may affect biological and geochemical processes as well as the pelagic and benthic ecosystem and fisheries productivity (Boehlert and Genin, 1987; Lavelle and Mohn, 2010; Rogers, 1994; Royer, 1978). Several studies have suggested that ecosystem at seamounts are highly productive (Fedosova, 1974; Rogers, 1994; Tseitlin, 1985; Uda and Ishino, 1958)

4.2 Plankton acoustic survey

The acoustic surveys were using the available frequencies on the research vessel, the 38 kHz and 200 kHz frequencies for trying to estimate the abundance and distribution of zooplankton around the seamount. Particular difficulties of estimating zooplankton abundance with acoustic instruments may occur if the density of phytoplankton is high, and in particular of some of these are gas producing or gas bearing (Mair et al., 2005; Selivanovsky and Ezersky, 1996; Selivanovsky et al., 1996). In the Andaman Sea, the population of phytoplankton is high with different species composition and abundance all along depth intervals where light is available above a certain intensity, but usually with highest density at

the surface layers (Boonyapiwat, 2006; Boonyapiwat et al., 2008; Nootmorn et al., 2007; Patarajinda et al., 2007). Phytoplankton samples were actually collected in this study but the abundance was not measured quantitatively as this was outside the scope of my study. However, a few samples were identified. The results showed very high species diversity and abundance throughout depths interval. Boonyapiwat et al. (2008) indicated the density of phytoplankton varied from 171-11178x10^3 cell/m^3 in the offshore area in the Andaman Sea while there was 97-568 individuals/m^3 of zooplankton abundance at same area (Jithlang et al., 2008). In Addition, Patarajinda (2007) studied species and abundance of phytoplankton and zooplankton with water sampler around Surin Island at the Andaman Sea, showing phytoplankton densities of 1075-5557x10^3 cell/m^3 but 10-48x10^3 individuals/m^3 of zooplankton abundance. It seems that phytoplankton in these areas have exceedingly higher density than zooplankton. If some of these phytoplankton groups also carry small quantities of gas, a complete masking of the backscattering from the weaker and less numerous zooplanktons may occur. Other potentially disturbing factors may be suspended air bubbles, suspended sediments, and particular gradients of salinity causing abrupt changes in sound velocity of the water column might contribute to scattering acoustic energy. They may all cause increased difficulties in interpretation and scrutinizing of acoustic data (Lavery et al., 2007; Warren et al., 2003).

Moreover, the mixture in the zooplankton population which was analyzed in this study showed that copepods were the dominant taxon in the investigated area. The highest frequency available, the 200 kHz, should in this study detect copepods better than the 38 kHz. Even higher frequencies or using several higher frequencies in a multi-frequency mode might be more useful for detecting the small zooplankton and improve our ability to separate fish echoes and unwanted, disturbing or masking echoes from zooplankton targets. Multiple-frequency acoustic scattering techniques may increase the range of conditions under which frequency discrimination can be used for interpreting biological parameters, including animal size or abundance from acoustic backscattering data (Holliday et al., 2009; Holliday and Pieper, 1980; Holliday et al., 1989; Korneliussen and Ona, 2002; Mair et al., 2005; Martin et al., 1996; Pieper et al., 1990; Warren et al., 2003). In most of the present zooplankton acoustic investigations, multi-frequency echo sounder was used for separating and extracting the acoustic scattering from zooplankton and fish in mixed recordings (Korneliussen and Ona, 2002). Holliday et al. (2009) explained that high resolution sensors can be used to determine the critical time and space scales by describing diel seasonal and intra-annual variability in zooplankton biomass. Also, several studied supports the use of multiple frequencies (Brierley

et al., 1998; Kristensen and Dalen, 1986; Lavery et al., 2007; Lebourges-Dhaussy et al., 2009; Madureira et al., 1993b; McKelvey and Wilson, 2006). Ciekals (2011) explained that the copepod backscattering was very high at 333 kHz compared to 38-120 kHz and 200 kHz as also reported by Lavery et al. (2007). Copepods in millimeter size was weakly scattering even when highly abundant, and when it was responsible for the main biomass at the sampling location, their contribution to the backscattering was not evident, except for at highest frequency. The scattering then generally increased with increasing frequency across the interesting frequency range.

Furthermore, the density of plankton-like targets around seamount was similar and fairly stable outside area of pinnacle but the density evidently varied around the pinnacle area. Current circulation, hydrography, ocean eddies, internal waves and turbulent mixing may all effect the plankton distribution seen after the water flow over the seamount. Circulation and turbulence as a mechanism forming the distribution might also help to maintain population distributions of plankton around the seamount (Genin and Boehlert, 1985; Lavelle and Mohn, 2010). Beckmann and Mohn (2002) described that if the seamount is tall, the seamount-initiated turbulence can help mix the water column all the way to the surface and small spatial scale turbulence variations can push on plankton patchiness above seamounts. Migrating zooplankton may also interact with shallow seamounts, owing to patchiness in the zooplankton distribution (Genin et al., 1994; Genin et al., 1988; Isaac and Schwartzlose, 1965). As result, the horizontal distribution of the plankton in September and October showed similar pattern at all transect lines with sharp decreased density at pinnacle area at both frequencies. The same pattern is also seen in some of the August transects. This is consistent with results obtained with reduced abundances of zooplankton above the summits of the eastern North Pacific seamounts (Genin et al., 1994; Genin et al., 1988; Haury et al., 2000) and several observations where it is described that zooplankton abundance decreased over the seamount (Dower and Mackas, 1996; Rogers, 1994). Also, Genin and Dower (2007) reported that biomass of the seamount zooplankton in many case is lower above the pinnacle than in the surrounding water area, especially over shallow seamounts based on the trophic enrichment over seamounts. Vertically migrating zooplankton in the early morning is a major mechanism for accumulation and trophic focusing over seamounts in shallow and middle depths, the zooplankton being consumed by fishes. Also, horizontal fluxes of planktonic prey and high fluxes are maintained due to current and internal waves over the seamounts.

4.3 Fish at pinnacle of seamount

This study indicates that 98% of fish was found closer than 0.1 nautical miles from the pinnacle of seamount. The trends could be interpreted as if the seamount area is a place with a high food supply and a high diversity habitat compared to the oceanic deeper water. Typical seamounts can therefore support rich stocks of pelagic and demersal fishes (Hubbs, 1959; Sasaki, 1986; Uchida and Tagami, 1984; Uda and Ishino, 1958) and extremely large stocks of commercial fishes at intermediate and a fewer deep seamounts (Clark, 2001; Rogers, 1994; Uchida and Tagami, 1984). Genin (2004) claims that seamounts support abundant populations of nekton and are usually associated with increased fish biomass when compared to the surrounding open ocean, often maintaining high standing stocks of demersal fishes (Boehlert and Genin, 1987). Possible reasons for the high productivity or transfer efficiency is due to current circulation with ocean eddies, internal waves and turbulent mixing causing enhanced primary production, subsequently leading to enhanced zooplankton stocks which further supports nektonic stocks over seamounts such as fishes (Boehlert, 1988; Boehlert and Genin, 1987; Dower and Mackas, 1996; Fock et al., 2002; Hubbs, 1959; Pereyra, 1969; Roden, 1987; Uda and Ishino, 1958).

The echogram at the seamount showed holes in the plankton layer after the school of fish, usually at the peak of pinnacle. It could be inferred that the interaction between current flow, local topography and diel vertical migration of zooplankton also interacts with predation from fish resident on the seamount (Genin et al., 1994; Genin et al., 1988; Haury et al., 1995; Rogers, 1994). The biomass of fish was approximately 18 tons with a fairly large uncertainty of ± 9.90 tons, and the abundance measured in the three periods is not significantly different ($p=0.17$). The stomach content was qualitatively investigated on about 50 fishes, showing mainly (80%) euphausiid (krill).

4.4 Comparison of acoustically measured zooplankton abundance and biologically sampled abundance

The result of zooplankton abundance investigations showed low correlation between acoustic measurements and biological sampling. The results indicates that there is significant errors involved, problems and limitations on the acoustic detection of the main zooplankton groups, but also with the two sampling devices used.

Several studies of zooplankton abundance and distribution have compared the acoustic method with net sampling. Johnson and Griffiths (1990) compared biomass and distribution of zooplankton sampled with hydroacoustics and Bongo net in the Beaufort Sea showing

weak relationships between volume scattering and zooplankton net biomass. The result is similar to the findings in our study. In another investigation, the volume backscatter was not directly related to zooplankton biomass studied at the continental shelf of Oregon, USA (Sutor and Cowles, 2005). This is also consistent with result obtained by Iida (1996) indicating roughly a correlation at each frequency with the measured S_V and the biological density. Kasatkina et al.(2004), also described difficulties in comparing net and acoustic abundance estimates in the Scotia Sea in both small scale and large scale structures.

From our zooplankton abundance estimation, the echoes scrutinized as zooplankton could not have been zooplankton, and the main smoke-like targets and layers must have been gas bearing phytoplankton rather than echoes from zooplankton. The high backscattering at both frequencies, and particularly at the 38 kHz, must be due to the phytoplankton in the Andaman Sea which is very high in species composition and abundance (Boonyapiwat, 2006; Boonyapiwat et al., 2008; Nootmorn et al., 2007; Patarajinda et al., 2007). Here, it is less probable that other disturbing factors, like suspended air bubbles, suspended sediments, gradients of salinity, might contributed to the backscattering, known to affect the quality of the acoustic data (Lavery et al., 2007; Warren et al., 2003). The situation in the surveys around the pinnacle in the Andaman Sea more resembles the situations from the North Sea described by Ciekals (2011) and by Mair et al. (2005), where the copepod backscattering is more or less masked by the scattering from phytoplankton at several of the operating frequencies.

The patchy distribution of zooplankton, especially for copepods, which is the dominant group, could be a likely error in abundance estimation in this study. This could be difficult to detect with the present instrumentation and in the catch by the biological sampling gear when sampling in fixed depths in the water column. Folt et al. (1999) described the plankton in ocean areas to be quite patchy distributed and that spatial heterogeneously was typical in plankton ecology and evolution. Zooplankton aggregations derives from the influence patchiness has on species interaction, population dynamic and community function. The most important behavioral traits of zooplankton patchiness are comprised in diel vertical migration, predator avoidance, finding food and mating. This is consistent with several studies of patchiness in zooplankton distributions above seamounts (Beckmann and Mohn, 2002; Genin et al., 1994; Genin et al., 1988; Isaac and Schwartzlose, 1965). Patchiness in the horizontal distribution of zooplankton or copepods can also be a serious problem when collecting samples for comparing the same population with acoustics and biological sampling (Ciekals, 2011; Holliday and Pieper, 1995).

Possible errors in biological sampling with both of the sampling devices used, the Bongo net and Van Dorn water sampler may also occur, especially with respect to animal size, and potential avoidance. The Bongo net was the main gear for collecting mesoplankton and fish larvae which is larger than 330 μm size. The large size zooplankton was sampled with good efficiency, but not the smaller ones. This gear was towed horizontally in several each depth intervals. Based on a patchy distribution of zooplankton, it might be difficult to catch populations which are distributed in other depths, like for example in thin layers. Also, if the zooplankton is aggregated in clumps or schoals with limited depth distributions, it is difficult to obtain a representative density sample with the Bongo net. However, if the zooplankton population is homogenously distributed, vertically and horizontally, the sampling accuracy for the larger mesoplankton is assumed to be good. The main reason for the difference in the numerical densities observed with the two sampling gears is animal size. For larger zooplankton, such as larvae of decapoda, and fish larvae with strong swimming capacity may also avoid the Bongo net (Iida et al., 1996).

The Van Dorn water sampler collects only a 20 liter water sample which is filtered through 50 μm mesh plankton net. Smaller sized zooplankton, such a microzooplankton was therefore only collected with this gear. This caused the apparent higher abundance recorded than for the Bongo, owing mostly to the difference in groups and sizes of the zooplankton. Also, large zooplankton with strong swimming capacity was rarely sampled within the small water sample. The larger zooplankton can easily avoid the sampler, before and during closing. If the large zooplankton does avoid the net or the water sampler, the abundance of zooplankton in both devices will be underestimated.

The zooplankton abundance collected with both of the biological sampling gears was compared to previous studies with the same gear in close areas of the seamount in the Andaman Sea. They showed more or less similar abundance, including for the Bongo net measurement with 68-622 individuals/m^3 at 10 m depth in this study and 97-568 individuals/m^3 at surface depth in the same area (Jithlang et al., 2008). Further, Van Dorn water sampler gear this study ranged from 1300-6100 individuals/m^3 and zooplankton abundance at Surin Island in the Andaman Sea was higher, with densities from 10000 to 48000 individuals/m^3 (Patarajinda et al., 2007).

Therefore, acoustic instruments may have the ability estimate abundance and rapidly map the distribution of good scatterers at large scale including horizontal and vertical distribution without disturbing the organisms. However, the target populations must either as single or multiple organisms give a backscattering well above the background noise level at

preferably several frequencies. The echo from of other, unwanted targets, like phytoplankton bubbles and suspended sediments must be significantly lower than the echoes from the target population if separation shall be possible. These conditions are probably not fulfilled here, where the density of the target population, copepods, was low, and the echo from similar disturbing targets are high. Conversely, the net sampling method may with advantage be used when studying species composition, density and distribution on a smaller scale or in specific study areas. Flagg and Smith (1989) described that zooplankton acoustic surveys may, if the primary conditions are fulfilled, cover a large volume of water, and are be more rapid than net sampling and layers or aggregations may be better described than by net sampling. Only in a few echograms, here given as examples of irregular echograms, could we clearly see indications of potential zooplankton backscattering where the frequency response was in more agreement with the zooplankton backscattering models than for the rest of the registrations of plankton- like targets.

5. Conclusions and future studies

In summary, the results indicate that the zooplankton densities in the study area of the Andaman Sea are very low. The copepod abundance in the investigation area was approximately 100-500 times lower than for comparable situations in the North Sea and Barents Sea. The acoustic measurement using only the 38 kHz and 200 kHz echo sounder frequencies made it difficult to distinguish them on the echograms and to separate them from other masking targets. The abundance estimation assumes that the target strength of a single copepod at 200 kHz is nearly 1000 times stronger (+30 dB) than at the 38 kHz. Nevertheless, at 200 kHz the echo is still too weak for detection of a single individual and multiple targets in the acoustic resolution volume is needed for proper detection. If the target strength modeling is correct, about 1000 individuals per cubic meter is needed before the echo is large enough (S_v > -100 dB re 1 m^3) for a clear detection.

Most of the investigations in zooplankton acoustics have dealt with measurements on euphausiids (krill) which are much larger and therefore have stronger backscattering scattering at 200 kHz than copepods. One individual euphausiid can be detected and measured with the 200 kHz system if there are few disturbing echoes in the water column. In this study, however, the abundance of krill was very low, and they could not be scrutinized from the echograms. From the scattering layers observed, the main smoke-like target and layers, expected to be very small targets like copepods or other tiny zooplankton, were concluded not to be copepods, as they were inconsistent with abundance of zooplankton sampled by the biological sampling. The area backscattering coefficient measured was also too high at both frequencies. It is therefore concluded that the scattering layers must have been caused by gas bearing phytoplankton rather than zooplankton. These are known to give variable and strong backscattering at both frequencies.

Phytoplankton data was collected in this study, but have not been analyzed as part of this investigation. Qualitative investigations of the samples show a high phytoplankton diversity and abundance, supporting the assumptions made. Future investigations should be able to correlate the phytoplankton abundance with the acoustic data, and to isolate the phytoplankton group or groups responsible for air-bubble generation. Further plankton acoustic investigations on the pinnacle should focus on finding the euphausiid populations, clearly present in good quantities when using the fish stomach analysis as a reference. Maybe some of the aggregations of plankton-like targets in the peculiar echograms presented are a key here?

If copepod abundance is further tried measured acoustically, a higher frequency than 200 kHz should be used. The standard available 333 kHz and 710 kHz may both cover the depths in the investigation area, but backscattering of phytoplankton on these frequencies might also mask some of the zooplankton echoes. If there is not a seasonal drop in primary production, removing some of the masking layers, the copepod abundance is probably best measured with traditional sampling devices, also in the future.

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7. Appendixes

Appendix 1. *Species composition and density of zooplankton sampled with Bongo net from 10 samples belong to 2 sampling sites during day and night between August-October 2011.*

No.	Taxa/Species	August			September				October		
		Site 1 Day 60 m	Site 1 Night 10 m	Site 2 Day 60 m	Site 1 Day 60 m	Site 1 Night 50 m	Site 2 Day 60 m	Site 2 Night 10 m	Site 1 Day 60 m	Site 2 Day 60 m	Site 2 Night 60 m
	Phylum Sacomastigophora										
	Subphylum Sarcodina										
	Class Granuloreticulosea										
	Order Foraminifera										
1	Unidentified planktonic foraminifera	18	27	9	19	6	7	24	4	6	8
	Phylum Cnidaria	0	0	0	0	0	0	0	0	0	0
	Superclass Hydrozoa	0	0	0	0	0	0	0	0	0	0
2	Unidentified hydrozoan	2	2	3	2	0	1	2	1	2	2
	Class Hydroidomedusae	0	0	0	0	0	0	0	0	0	0
	Subclass Anthomedusae	0	0	0	0	0	0	0	0	0	0
	Family Bougainvilliidae	0	0	0	0	0	0	0	0	0	0
3	*Bougainvillia* sp.	1	1	0	0	0	0	0	0	2	1
	Family Cytaeididae	0	0	0	0	0	0	0	0	0	0
4	*Cytaeis* sp.	0	0	0	0	0	0	0	0	0	1
	Subclass Leptomedusae	0	0	0	0	0	0	0	0	0	0
	Family Laodiceidae	0	0	0	0	0	0	0	0	0	0
5	*Laodicea* sp.	0	1	0	0	0	0	0	0	0	1
	Subclass Trachymedusae	0	0	0	0	0	0	0	0	0	0
	Family Geryoniidae	0	0	0	0	0	0	0	0	0	0
6	*Liriope* sp.	0	0	0	0	0	1	0	0	0	0
	Class Siphonophora	0	0	0	0	0	0	0	0	0	0
	Subclass Siphonophorae	0	0	0	0	0	0	0	0	0	0
	Order Calycophorae	0	0	0	0	0	0	0	0	0	0
	Family Hippopodiidae	0	0	0	0	0	0	0	0	0	0
7	*Hippopodius* sp.	0	0	0	0	1	0	0	0	0	0
	Family Diphyidae	0	0	0	0	0	0	0	0	0	0
8	*Diphyes* sp.	12	9	13	1	0	1	7	2	3	4
9	*Lensia* sp.	0	0	0	0	2	0	0	0	0	0

Appendix 1. *(Cont.)*

No.	Taxa/Species	August			September				October		
		Site 1 Day 60 m	Site 1 Night 10 m	Site 2 Day 60 m	Site 1 Day 60 m	Site 1 Night 50 m	Site 2 Day 60 m	Site 2 Night 10 m	Site 1 Day 60 m	Site 2 Day 60 m	Site 2 Night 60 m
	Family Abylidae	0	0	0	0	0	0	0	0	0	0
10	*Abyla* sp.	2	1	0	0	0	0	0	0	0	0
11	*Abylopsis* sp.	1	0	1	2	1	0	0	2	0	2
12	*Bassia* sp.	0	0	0	0	1	0	0	0	1	0
	Phylum Annelida	0	0	0	0	0	0	0	0	0	0
	Class Polychaeta	0	0	0	0	0	0	0	0	0	0
13	Polychaete larvae	0	0	1	2	0	1	0	0	1	1
	Phylum Mollusca	0	0	0	0	0	0	0	0	0	0
	Class Gastropoda	0	0	0	0	0	0	0	0	0	0
14	Gastropod larvae	6	2	5	20	1	6	30	5	2	5
	Family Cavoliniidae	0	0	0	0	0	0	0	0	0	0
15	*Creseis* sp.	1	1	0	4	1	1	13	1	1	1
	Class Bivalvia	0	0	0	0	0	0	0	0	0	0
16	Bivalve larvae	4	3	8	5	0	3	4	2	1	2
	Class Cephalopoda	0	0	0	0	0	0	0	0	0	0
17	Cephalopod larvae	0	0	0	0	1	0	0	0	0	1
	Phylum Echinodermata	0	0	0	0	0	0	0	0	0	0
	Class Echinoidea	0	0	0	0	0	0	0	0	0	0
18	Echinopluteus larvae	0	0	0	0	0	1	0	0	1	1
	Class Ophiuroidea	0	0	0	0	0	0	0	0	0	0
19	Ophiopluteus larvae	22	8	50	3	3	0	8	1	2	3
	Phylum Arthropoda	0	0	0	0	0	0	0	0	0	0
	Subclass Branchiopoda	0	0	0	0	0	0	0	0	0	0
	Order Onychopoda	0	0	0	0	0	0	0	0	0	0
	Family Podonidae	0	0	0	0	0	0	0	0	0	0
20	*Evadne* spp.	9	6	1	0	0	0	0	0	0	0
	Subclass Ostracoda	0	0	0	0	0	0	0	0	0	0
21	Unidentified ostracods	32	7	22	22	23	33	31	10	21	10
	Subclass Copepoda	0	0	0	0	0	0	0	0	0	0
	Order Calanoida	0	0	0	0	0	0	0	0	0	0
22	Calanoid copepodid	2	0	2	0	0	0	8	6	4	5

Appendix 1. *(Cont.)*

No.	Taxa/Species	August			September				October		
		Site 1 Day 60 m	Site 1 Night 10 m	Site 2 Day 60 m	Site 1 Day 60 m	Site 1 Night 50 m	Site 2 Day 60 m	Site 2 Night 10 m	Site 1 Day 60 m	Site 2 Day 60 m	Site 2 Night 60 m
	Superfamily Arietelloidea	0	0	0	0	0	0	0	0	0	0
	Family Lucicutiidae	0	0	0	0	0	0	0	0	0	0
23	*Lucicutia* sp.	29	2	17	3	0	19	4	11	4	3
	Superfamily Centropagoidea	0	0	0	0	0	0	0	0	0	0
	Family Acartiidae	0	0	0	0	0	0	0	0	0	0
24	*Acartia* spp.	38	40	2	17	2	0	23	3	5	5
	Family Candaciidae	0	0	0	0	0	0	0	0	0	0
25	*Candacia* sp.	7	3	8	10	2	16	4	1	4	3
26	*Paracandacia* sp.	0	0	0	3	6	0	0	0	0	0
	Family Centropagidae	0	0	0	0	0	0	0	0	0	0
27	*Centropages* spp.	2	3	13	7	0	3	8	1	3	1
	Family Pontellidae	0	0	0	0	0	0	0	0	0	0
28	*Calanopia* sp.	0	2	8	0	0	54	19	0	4	1
29	*Pontella* sp.	0	0	0	0	0	3	0	0	0	0
30	*Pontellina* sp.	2	0	0	0	0	0	0	0	0	0
	Family Pseudodiaptomidae	0	0	0	0	0	0	0	0	0	0
31	*Pseudodiaptomus* sp.	0	0	0	3	0	0	0	0	0	0
	Family Temoridae	0	0	0	0	0	0	0	0	0	0
32	*Temora* sp.	2	10	2	0	6	0	27	4	3	5
	Superfamily Megacalanoidea	0	0	0	0	0	0	0	0	0	0
	Family Calanidae	0	0	0	0	0	0	0	0	0	0
33	*Canthocalanus* sp.	0	8	0	27	6	92	57	20	34	5
34	*Undinula* sp.	7	2	4	10	9	16	8	2	6	1
	Family Paracalanidae	0	0	0	0	0	0	0	0	0	0
35	*Acrocalanus* spp.	11	3	6	20	4	35	34	10	19	5
36	*Paracalanus* spp.	9	2	6	7	6	54	42	4	18	5
	Family Calocalanidae	0	0	0	0	0	0	0	0	0	0
37	*Calocalanus* sp.	0	0	2	0	1	0	0	2	0	1
	Superfamily Eucalanoidea	0	0	0	0	0	0	0	0	0	0
	Family Eucalanidae	0	0	0	0	0	0	0	0	0	0
38	*Pareucalanus* sp.	0	0	2	0	0	0	0	0	0	0
39	*Subeucalanus* sp.	4	1	25	7	4	0	42	2	4	11

Appendix 1. *(Cont.)*

No.	Taxa/Species	August			September				October		
		Site 1 Day 60 m	Site 1 Night 10 m	Site 2 Day 60 m	Site 1 Day 60 m	Site 1 Night 50 m	Site 2 Day 60 m	Site 2 Night 10 m	Site 1 Day 60 m	Site 2 Day 60 m	Site 2 Night 60 m
	Superfamily Clausocalanoidea	0	0	0	0	0	0	0	0	0	0
	Family Clausocalanidae	0	0	0	0	0	0	0	0	0	0
40	*Clausocalanus* sp.	4	2	11	0	0	35	4	8	9	0
	Family Euchaetidae	0	0	0	0	0	0	0	0	0	0
41	*Euchaeta* spp.	46	11	27	127	12	126	161	30	25	11
	Family Scolecithricidae	0	0	0	0	0	0	0	0	0	0
42	*Scolecithricella* sp.	0	0	0	0	0	3	0	0	1	0
	Order Cyclopoida	0	0	0	0	0	0	0	0	0	0
	Family Oithonidae	0	0	0	0	0	0	0	0	0	0
43	*Oithona* spp.	5	2	7	23	6	3	31	6	6	10
	Order Poecilostomatoida	0	0	0	0	0	0	0	0	0	0
	Family Corycaeidae	0	0	0	0	0	0	0	0	0	0
44	*Corycaeus* spp.	44	2	8	6	6	6	8	7	11	8
	Family Oncaeidae	0	0	0	0	0	0	0	0	0	0
45	*Oncaea* sp.	60	16	29	68	23	33	12	36	24	18
	Family Sapphirinidae	0	0	0	0	0	0	0	0	0	0
46	*Copilia* spp.	0	0	0	0	1	0	0	1	1	1
47	*Sapphirina* spp.	0	0	0	0	1	0	0	0	0	1
	Order Harpacticoida	0	0	0	0	0	0	0	0	0	0
	Family Miraciidae	0	0	0	0	0	0	0	0	0	0
48	*Macrosetella* sp.	2	0	1	0	0	0	0	1	0	0
	Class Malacostraca	0	0	0	0	0	0	0	0	0	0
	Superorder Percarida	0	0	0	0	0	0	0	0	0	0
	Order Mysidacea	0	0	0	0	0	0	0	0	0	0
49	Unidentified mysid	0	0	0	2	0	1	0	1	1	3
	Order Amphipoda	0	0	0	0	0	0	0	0	0	0
	Suborder Hyperiidae	0	0	0	0	0	0	0	0	0	0
50	Unidentified hyperiids	5	1	0	11	3	1	1	6	3	2
	Superorder Eucarida	0	0	0	0	0	0	0	0	0	0
	Order Euphausiacaea	0	0	0	0	0	0	0	0	0	0
51	Euphausiid larvae	2	1	1	2	1	1	0	2	6	2
	Family Euphausiidae	0	0	0	0	0	0	0	0	0	0
52	*Euphausia* sp.	0	1	0	1	0	1	2	0	1	0

Appendix 1. *(Cont.)*

No.	Taxa/Species	August			September				October		
		Site 1 Day 60 m	Site 1 Night 10 m	Site 2 Day 60 m	Site 1 Day 60 m	Site 1 Night 50 m	Site 2 Day 60 m	Site 2 Night 10 m	Site 1 Day 60 m	Site 2 Day 60 m	Site 2 Night 60 m
	Superorder Hoplocarida	0	0	0	0	0	0	0	0	0	0
	Order Stomatopoda	0	0	0	0	0	0	0	0	0	0
53	Alima larvae	0	0	1	0	0	0	0	1	0	1
	Superorder Eucarida	0	0	0	0	0	0	0	0	0	0
	Order Decapoda	0	0	0	0	0	0	0	0	0	0
	Suborder Dendrobranchiata	0	0	0	0	0	0	0	0	0	0
	Family Luciferidae	0	0	0	0	0	0	0	0	0	0
54	*Lucifer* protozoea	0	0	0	0	1	0	1	1	1	0
55	*Lucifer* mysis	0	0	1	0	0	0	0	1	0	0
56	*Lucifer* spp.	0	0	1	1	0	0	0	1	0	1
	Family Sergestidae	0	0	0	0	0	0	0	0	0	0
57	Sergestid larvae	0	0	1	1	1	0	0	0	2	1
	Suborder Pleocyemata	0	0	0	0	0	0	0	0	0	0
	Infraorder Brachyura	0	0	0	0	0	0	0	0	0	0
58	Brachyuran larvae	1	1	1	1	1	1	0	1	0	1
	Infraorder Caridea	0	0	0	0	0	0	0	0	0	0
59	Caridean larvae	1	1	1	7	1	1	0	2	2	2
	Infraorder Anomura	0	0	0	0	0	0	0	0	0	0
60	Anomuran larvae	1	1	3	3	1	1	1	6	3	4
	Infraorder Palinuridea	0	0	0	0	0	0	0	0	0	0
61	Porcellanid larvae	0	0	0	2	0	0	0	0	0	0
	Phylum Chaetognatha	0	0	0	0	0	0	0	0	0	0
	Class Sagittoidea	0	0	0	0	0	0	0	0	0	0
	Order Aphragmophora	0	0	0	0	0	0	0	0	0	0
	Family Sagittidae	0	0	0	0	0	0	0	0	0	0
62	*Sagitta* spp.	6	6	26	22	5	5	9	8	8	10
	Phylum Chordata	0	0	0	0	0	0	0	0	0	0
	Subphylum Urochordata (Tunicata)	0	0	0	0	0	0	0	0	0	0
	Class Appendicularia	0	0	0	0	0	0	0	0	0	0
	Family Oikopleuridae	0	0	0	0	0	0	0	0	0	0
63	*Oikopleura* spp.	1	1	2	4	3	1	0	1	6	4

Appendix 1. *(Cont.)*

No.	Taxa/Species	August			September				October		
		Site 1 Day 60 m	Site 1 Night 10 m	Site 2 Day 60 m	Site 1 Day 60 m	Site 1 Night 50 m	Site 2 Day 60 m	Site 2 Night 10 m	Site 1 Day 60 m	Site 2 Day 60 m	Site 2 Night 60 m
	Class Thaliacea	0	0	0	0	0	0	0	0	0	0
	Order Doliolida	0	0	0	0	0	0	0	0	0	0
	Family Doliolidae	0	0	0	0	0	0	0	0	0	0
64	*Doliolum* spp.	1	0	0	0	0	0	0	1	2	1
	Order Salpida	0	0	0	0	0	0	0	0	0	0
	Family Salpidae	0	0	0	0	0	0	0	0	0	0
65	*Salpa* spp.	0	0	0	0	0	0	0	0	1	1
	Subphylum Vertebrata	0	0	0	0	0	0	0	0	0	0
	Class Actionopterygii	0	0	0	0	0	0	0	0	0	0
	Division Teleostei	0	0	0	0	0	0	0	0	0	0
66	Family Ambassidae	0	0	0	0	0	0	0	0	1	1
67	Family Blenniidae	1	0	0	0	0	0	0	0	0	0
68	Family Bregmacerotidaedae	0	0	0	0	0	0	0	1	0	1
69	Family Clupeidae	0	0	0	1	0	0	0	0	0	0
70	Family Engraulidae	0	0	0	0	0	0	0	0	0	1
71	Family Gobiidae	0	0	1	0	0	0	0	0	0	0
72	Family Labridae	0	0	1	0	0	0	0	0	0	0
73	Family Lutjanidae	0	0	0	0	0	0	0	0	0	1
74	Family Nemipteridae	0	1	1	0	0	0	0	0	0	1
75	Family Sciaenidae	0	0	0	0	0	0	0	0	0	1
76	Family Scombridae	0	0	0	0	0	1	0	0	0	0
77	Family Sphyraenidae	0	0	0	0	0	0	0	0	0	1
78	Family Synodontidaedae	0	0	0	0	0	0	0	0	0	1
	Total zooplankton	**402**	**193**	**334**	**471**	**152**	**564**	**622**	**214**	**265**	**180**

Appendix 2. *Zooplankton taxa and density sampled with Bongo net from 2 sampling sites during day and night between August-October 2011.*

No.	Zooplankton Taxa	August																	
		Sampling Site 1												Sampling Site 2					
		Day						Night						Day					
		10 m	20 m	30 m	40 m	50 m	60 m	10 m	20 m	30 m	40 m	50 m	60 m	10 m	20 m	30 m	40 m	50 m	60 m
1	Foraminifera	86	83	40	22	6	20	29	68	13	4	10	36	157	140	35	9	50	16
2	Cnidaria	12	5	17	7	1	19	13	7	0	1	3	5	22	10	13	6	8	18
3	Polychaeta	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
4	Gastropoda	0	3	1	18	0	8	3	0	1	0	0	2	7	2	0	1	2	5
5	Bivalvia	0	16	1	24	1	4	3	4	4	7	5	0	13	10	18	4	2	8
6	Cephalopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Echinodermata	5	33	9	18	1	22	8	3	3	31	10	5	0	7	31	11	46	50
8	Marine Cladocera	6	2	1	0	1	9	6	4	3	1	1	1	8	1	0	1	2	0
9	Ostracoda	0	0	1	4	5	32	7	28	8	14	9	9	0	0	1	3	7	22
10	Calanoida	81	40	42	34	39	162	89	87	46	66	1	103	109	76	40	28	74	133
11	Cyclopoida	5	1	7	4	0	5	2	0	2	3	0	1	3	1	7	5	14	7
12	Poecilostomatoida	9	5	3	0	21	104	21	7	4	5	7	8	0	3	3	3	8	36
13	Harpacticoida	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
14	Malacostraca	9	13	20	9	3	8	5	19	4	1	13	8	14	7	8	6	13	9
15	Chaetognatha	6	5	5	9	5	6	6	3	7	9	8	4	7	7	5	9	1	26
16	Urochordata (Tunicata)	0	0	2	0	0	2	0	0	0	0	0	0	3	2	1	1	1	0
17	Fish larvae	1	0	1	2	0	0	0	2	0	4	3	0	1	1	0	1	1	2
	Total zooplankton	**221**	**206**	**149**	**149**	**83**	**402**	**193**	**233**	**95**	**146**	**70**	**182**	**346**	**269**	**162**	**88**	**232**	**334**

Appendix 2. *(Cont.)*

No.	Zooplankton Taxa	September											
		Sampling Site 1											
		Day						Night					
		10 m	20 m	30 m	40 m	50 m	60 m	10 m	20 m	30 m	40 m	50 m	60 m
1	Foraminifera	4	22	2	16	13	23	3	14	13	24	10	20
2	Cnidaria	3	3	0	3	7	4	8	4	2	1	3	6
3	Polychaeta	0	0	0	0	0	2	0	0	0	0	0	0
4	Gastropoda	6	0	4	0	4	24	0	6	2	2	3	3
5	Bivalvia	3	0	2	0	1	5	3	4	2	1	0	1
6	Cephalopoda	0	0	0	0	0	0	0	0	0	0	0	0
7	Echinodermata	1	0	0	3	0	3	1	0	6	3	3	6
8	Marine Cladocera	0	0	0	0	0	0	0	0	1	0	0	0
9	Ostracoda	2	5	0	4	4	22	10	32	13	7	26	42
10	Calanoida	51	145	33	35	91	241	128	148	79	84	57	81
11	Cyclopoida	2	13	7	3	6	23	0	4	1	5	6	13
12	Poecilostomatoida	81	171	24	12	11	74	28	74	44	21	31	28
13	Harpacticoida	0	0	0	0	0	0	0	0	0	0	0	0
14	Malacostraca	5	9	4	8	17	28	7	4	6	6	8	3
15	Chaetognatha	0	7	1	5	13	22	4	8	3	3	5	4
16	Urochordata (Tunicata)	1	0	0	2	0	0	0	3	0	0	0	0
17	Fish larvae	0	0	0	1	1	1	0	3	2	0	0	1
Total zooplankton		**161**	**374**	**75**	**92**	**167**	**471**	**191**	**303**	**175**	**157**	**152**	**207**

Appendix 2. *(Cont.)*

No.	Zooplankton Taxa	September											
		Sampling Site 2											
		Day						Night					
		10 m	20 m	30 m	40 m	50 m	60 m	10 m	20 m	30 m	40 m	50 m	60 m
1	Foraminifera	5	20	13	18	2	9	24	10	1	8	11	4
2	Cnidaria	1	1	1	3	0	2	9	5	1	4	6	5
3	Polychaeta	0	0	0	0	0	0	0	0	0	0	1	0
4	Gastropoda	1	0	4	3	1	6	43	7	0	0	11	0
5	Bivalvia	3	1	6	2	1	3	4	2	0	0	5	1
6	Cephalopoda	0	0	0	0	0	0	0	0	0	0	1	0
7	Echinodermata	0	8	6	4	2	0	8	3	2	0	8	1
8	Marine Cladocera	0	0	0	0	0	0	0	0	0	0	0	0
9	Ostracoda	1	1	1	0	19	35	31	13	5	9	15	15
10	Calanoida	44	58	21	40	260	455	440	166	68	99	59	33
11	Cyclopoida	1	7	0	0	1	3	31	16	2	2	4	6
12	Poecilostomatoida	5	4	1	8	30	39	20	12	5	9	11	7
13	Harpacticoida	0	0	0	0	0	0	0	0	0	0	1	0
14	Malacostraca	4	2	1	4	0	7	5	3	3	4	3	3
15	Chaetognatha	0	2	3	7	21	5	9	2	2	4	5	2
16	Urochordata (Tunicata)	4	3	0	2	0	0	0	0	0	0	1	0
17	Fish larvae	1	2	1	0	1	0	0	0	0	0	0	1
	Total zooplankton	**68**	**107**	**62**	**90**	**337**	**564**	**622**	**240**	**89**	**140**	**140**	**79**

Appendix 2. *(Cont.)*

No.	Zooplankton Taxa	October																	
		Sampling Site 1						Sampling Site 2											
		Day						Day						Night					
		10 m	20 m	30 m	40 m	50 m	60 m	10 m	20 m	30 m	40 m	50 m	60 m	10 m	20 m	30 m	40 m	50 m	60 m
1	Foraminifera	11	9	16	22	27	5	3	1	10	5	5	10	25	18	14	6	20	11
2	Cnidaria	5	6	15	18	9	5	7	2	6	3	7	9	9	5	14	11	12	8
3	Polychaeta	1	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0
4	Gastropoda	0	0	4	1	2	0	0	0	2	3	2	3	3	4	2	1	1	8
5	Bivalvia	2	2	1	1	1	2	1	0	2	0	2	1	4	1	3	1	1	2
6	Cephalopoda	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
7	Echinodermata	3	0	1	6	8	0	0	0	0	2	3	3	0	2	1	3	4	3
8	Marine Cladocera	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0
9	Ostracoda	0	0	0	0	2	14	0	0	0	3	3	22	12	11	3	9	9	15
10	Calanoida	24	15	16	33	27	107	26	19	46	77	90	147	74	73	63	47	74	65
11	Cyclopoida	2	2	19	7	12	6	1	1	2	9	5	6	10	5	4	4	6	11
12	Poecilostomatoida	7	5	8	8	2	47	19	12	9	15	12	38	35	33	15	13	19	29
13	Harpacticoida	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	Malacostraca	4	3	4	1	4	19	3	2	5	11	7	18	8	6	16	14	21	14
15	Chaetognatha	11	1	5	16	19	8	3	2	7	9	9	9	7	14	15	8	12	11
16	Urochordata (Tunicata)	3	4	15	8	3	0	0	0	0	3	2	0	0	2	7	3	4	0
17	Fish larvae	0	0	1	0	3	0	0	1	0	0	0	0	0	1	2	1	3	3
	Total zooplankton	**73**	**46**	**103**	**123**	**118**	**214**	**63**	**40**	**89**	**138**	**147**	**265**	**190**	**173**	**159**	**119**	**187**	**180**

Appendix 3. *Zooplankton taxa and density sampled with Van Dorn water sampler from 2 sampling sites during day and night between August-October 2011.*

No.	Zooplankton Taxa	August																							
		Sampling Site 1																Sampling Site 2							
		Day								Night								Day							
		5 m	10 m	15 m	20 m	30 m	40 m	50 m	60 m	5 m	10 m	15 m	20 m	30 m	40 m	50 m	60 m	5 m	10 m	15 m	20 m	30 m	40 m	50 m	60 m
1	Foraminifera	200	50	350	250	0	0	0	0	300	50	150	250	50	0	0	0	450	150	350	300	450	50	0	0
2	Cnidaria	0	0	100	100	50	0	0	0	600	100	50	150	100	50	0	0	100	100	50	150	50	50	100	0
3	Polychaeta	100	100	150	50	0	0	0	50	0	100	100	200	150	50	100	0	0	50	50	0	150	150	50	0
4	Gastropoda	0	0	50	0	0	0	0	0	50	0	0	0	0	0	0	100	0	0	0	0	100	0	50	100
5	Bivalvia	0	0	250	0	0	50	0	0	150	100	50	50	0	0	0	100	100	100	350	0	0	50	0	50
6	Cephalopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Echinodermata	0	50	0	0	250	100	0	0	50	0	0	0	100	150	0	0	0	0	50	0	0	150	150	0
8	Marine Cladocera	0	0	0	0	0	0	0	0	850	0	0	0	50	0	0	0	50	50	50	0	0	0	0	0
9	Ostracoda	0	0	0	0	0	0	0	0	500	0	0	50	0	100	50	150	0	0	0	0	0	0	50	50
10	Calanoida	3,200	3,400	4,100	2,300	900	750	650	450	3,200	4,000	3,000	2,100	950	300	750	650	900	3,900	6,500	4,500	2,650	1,200	1,850	1,750
11	Cyclopoida	0	400	650	300	50	50	150	0	100	50	300	450	0	50	150	300	50	150	150	150	100	0	200	0
12	Poecilostomatoida	650	600	350	150	0	50	0	0	650	500	550	350	300	150	50	350	150	250	550	350	100	50	0	100
13	Harpacticoida	50	150	350	100	50	50	50	0	0	250	250	200	100	0	0	0	0	150	200	300	150	0	100	200
14	Malacostraca	0	0	0	0	0	0	0	50	1,000	50	50	0	50	0	100	200	0	0	50	150	0	50	0	50
15	Chaetognatha	50	100	100	100	100	0	2,500	0	100	100	100	0	50	200	0	100	0	100	100	150	50	0	50	0
16	Urochordata (Tunicata)	50	550	400	100	300	50	0	0	0	200	450	0	100	450	0	50	50	500	750	800	250	200	100	100
17	Fish larvae	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	50	50	0	0	50	0	0	0	0
	Total zooplankton	**4,300**	**5,400**	**6,850**	**3,450**	**1,700**	**1,100**	**3,350**	**550**	**7,550**	**5,500**	**5,050**	**3,800**	**2,050**	**1,500**	**1,200**	**2,050**	**1,900**	**5,500**	**9,200**	**6,900**	**4,050**	**1,950**	**2,700**	**2,400**

Appendix 3. *(Cont.)*

No.	Zooplankton Taxa	September															
		Sampling Site 1															
		Day								Night							
		5 m	10 m	15 m	20 m	30 m	40 m	50 m	60 m	5 m	10 m	15 m	20 m	30 m	40 m	50 m	60 m
1	Foraminifera	0	0	0	50	50	250	0	100	0	50	0	0	0	0	50	0
2	Cnidaria	0	50	0	0	0	0	0	0	50	50	0	50	50	0	0	100
3	Polychaeta	0	100	50	50	0	100	0	50	0	0	0	50	0	50	0	0
4	Gastropoda	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0
5	Bivalvia	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0
6	Cephalopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Echinodermata	0	0	0	0	0	50	0	0	0	0	0	0	0	100	0	50
8	Marine Cladocera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Ostracoda	0	0	0	50	400	300	0	0	50	0	50	100	0	0	200	50
10	Calanoida	300	650	4,650	3,500	2,700	700	2,050	1,500	3,250	4,600	3,150	2,850	2,350	1,500	1,500	1,900
11	Cyclopoida	0	0	100	150	200	50	150	250	50	0	100	200	50	0	150	350
12	Poecilostomatoida	50	150	250	700	200	50	100	100	100	450	400	250	250	200	200	50
13	Harpacticoida	0	100	0	100	0	0	0	0	0	550	350	200	100	50	100	0
14	Malacostraca	0	0	50	0	100	0	0	0	50	0	0	0	0	0	100	0
15	Chaetognatha	0	100	50	50	150	0	0	50	50	150	50	150	100	50	100	200
16	Urochordata (Tunicata)	0	150	550	500	0	0	750	200	450	250	350	150	350	250	500	0
17	Fish larvae	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0
	Total zooplankton	**350**	**1,300**	**5,700**	**5,250**	**3,800**	**1,500**	**3,100**	**2,250**	**4,050**	**6,100**	**4,500**	**4,000**	**3,250**	**2,200**	**2,900**	**2,700**

Appendix 3. *(Cont.)*

No.	Zooplankton Taxa	September															
		Sampling Site 2															
		Day								Night							
		5 m	10 m	15 m	20 m	30 m	40 m	50 m	60 m	5 m	10 m	15 m	20 m	30 m	40 m	50 m	60 m
1	Foraminifera	50	0	0	0	50	50	200	50	50	50	0	200	0	0	0	0
2	Cnidaria	0	50	100	0	0	0	0	0	50	50	0	150	0	100	50	50
3	Polychaeta	50	0	100	0	0	50	0	0	0	150	0	0	50	50	0	0
4	Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Bivalvia	0	50	0	0	0	0	0	0	0	50	0	0	0	0	0	50
6	Cephalopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Echinodermata	50	0	0	50	0	150	0	0	0	0	0	0	100	150	0	0
8	Marine Cladocera	0	0	0	50	100	0	0	0	0	0	0	0	0	0	0	50
9	Ostracoda	0	0	0	0	0	0	0	0	0	0	50	0	0	0	50	0
10	Calanoida	2,300	2,800	3,850	3,700	3,300	1,000	1,250	1,350	3,100	2,750	3,000	3,400	1,800	1,300	1,700	1,300
11	Cyclopoida	0	0	250	400	250	150	0	100	0	200	200	250	50	50	100	50
12	Poecilostomatoida	300	250	100	50	0	0	0	100	250	350	200	250	100	100	150	100
13	Harpacticoida	50	150	0	0	0	50	0	50	200	0	150	100	0	0	0	0
14	Malacostraca	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0
15	Chaetognatha	350	250	250	0	0	0	150	100	50	150	200	200	50	50	0	0
16	Urochordata (Tunicata)	250	150	0	200	150	200	50	0	100	300	0	250	0	200	250	150
17	Fish larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total zooplankton	**3,400**	**3,700**	**4,650**	**4,450**	**3,850**	**1,650**	**1,650**	**1,750**	**3,800**	**4,100**	**3,800**	**4,800**	**2,150**	**2,000**	**2,300**	**1,750**

Appendix 3. *(Cont.)*

No.	Zooplankton Taxa	October																							
		Sampling Site 1								Sampling Site 2															
		Day								Day								Night							
		5 m	10 m	15 m	20 m	30 m	40 m	50 m	60 m	5 m	10 m	15 m	20 m	30 m	40 m	50 m	60 m	5 m	10 m	15 m	20 m	30 m	40 m	50 m	60 m
1	Foraminifera	0	200	0	50	0	0	50	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	50	0
2	Cnidaria	0	0	0	0	0	50	50	50	0	0	100	0	0	150	50	150	0	100	0	50	50	100	150	150
3	Polychaeta	0	50	50	0	0	0	0	0	0	0	0	0	0	50	50	0	0	0	0	0	50	0	0	0
4	Gastropoda	0	0	0	0	0	0	0	50	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0
5	Bivalvia	0	0	0	0	0	0	0	50	0	0	0	50	0	0	50	0	50	0	0	50	0	0	0	0
6	Cephalopoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Echinodermata	0	0	50	50	0	50	0	0	0	0	0	0	0	0	50	0	50	0	0	0	0	0	0	50
8	Marine Cladocera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	Ostracoda	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	150	50	100	0
10	Calanoida	250	1,950	950	1,200	1,450	1,750	1,250	2,250	100	1,200	1,000	1,450	1,850	1,000	1,450	1,100	200	800	1,050	450	950	1,400	1,250	1,500
11	Cyclopoida	0	0	0	0	100	150	200	250	50	50	50	150	150	50	50	250	0	50	150	50	50	50	50	0
12	Poecilostomatoida	550	100	250	300	100	250	250	150	150	150	100	250	100	0	150	100	0	50	100	0	100	150	0	150
13	Harpacticoida	50	250	50	100	50	50	100	50	0	100	0	50	100	0	50	0	200	50	0	100	50	150	0	0
14	Malacostraca	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	50	0	0	0	0	0	0
15	Chaetognatha	50	150	100	50	0	100	50	50	0	50	200	100	0	150	200	0	300	50	50	100	50	50	100	50
16	Urochordata (Tunicata)	300	300	250	50	450	350	200	100	0	50	100	200	200	150	100	100	0	1,550	100	200	300	650	250	700
17	Fish larvae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total zooplankton	**1,200**	**3,000**	**1,700**	**1,800**	**2,150**	**2,750**	**2,150**	**3,100**	**300**	**1,600**	**1,550**	**2,300**	**2,550**	**1,550**	**2,200**	**1,700**	**800**	**2,700**	**1,450**	**1,000**	**1,750**	**2,600**	**1,950**	**2,600**

Appendix 4. *Total zooplankton abundance sampled with acoustical and biological sampling from 2 sampling sites during day and night between August-October 2011.*

Depth	Sampling Site 1 (Day)														
	August					September					October				
	s_A (38 kHz) (m^2/nmi^2)	s_A (200 kHz) (m^2/nmi^2)	Bongo (ind./m^3)	Van Dorn (ind./m^3)	Biomass (mg/m^3)	s_A (38 kHz) (m^2/nmi^2)	s_A (200 kHz) (m^2/nmi^2)	Bongo (ind./m^3)	Van Dorn (ind./m^3)	Biomass (mg/m^3)	s_A (38 kHz) (m^2/nmi^2)	s_A (200 kHz) (m^2/nmi^2)	Bongo (ind./m^3)	Van Dorn (ind./m^3)	Biomass (mg/m^3)
10	24	10	221	5400	0.0041	32	10	161	1300	0.0064	107	21	73	3000	0.0037
20	101	25	206	3450	0.0032	51	10	374	5250	0.0074	39	20	46	1800	0.0035
30	517	68	149	1700	0.0040	54	18	75	3800	0.0031	46	30	103	2150	0.0044
40	715	88	149	1100	0.0050	152	47	92	1500	0.0038	88	43	123	2750	0.0068
50	211	31	83	3350	0.0020	235	49	167	3100	0.0071	130	38	118	2150	0.0059
60	149	21	402	550	0.0062	142	16	471	2250	0.0184	232	36	214	3100	0.0113

Depth	Sampling Site 1 (Night)									
	August					September				
	s_A (38 kHz) (m^2/nmi^2)	s_A (200 kHz) (m^2/nmi^2)	Bongo (ind./m^3)	Van Dorn (ind./m^3)	Biomass (mg/m^3)	s_A (38 kHz) (m^2/nmi^2)	s_A (200 kHz) (m^2/nmi^2)	Bongo (ind./m^3)	Van Dorn (ind./m^3)	Biomass (mg/m^3)
10	127	45	193	5500	0.0043	78	21	191	6100	0.0085
20	207	45	233	3800	0.0022	192	36	303	4000	0.0104
30	373	71	95	2050	0.0030	164	44	175	3250	0.0083
40	512	146	146	1500	0.0038	168	53	157	2200	0.0103
50	518	107	70	1200	0.0037	263	67	152	2900	0.0104
60	264	47	182	2050	0.0032	152	46	207	2700	0.0089

Appendix 4. *(Cont.)*

Depth	Sampling Site 2 (Day)														
	August					September					October				
	s_A (38 kHz) (m^2/nmi^2)	s_A (200 kHz) (m^2/nmi^2)	Bongo (ind./m^3)	Van Dorn (ind./m^3)	Biomass (mg/m^3)	s_A (38 kHz) (m^2/nmi^2)	s_A (200 kHz) (m^2/nmi^2)	Bongo (ind./m^3)	Van Dorn (ind./m^3)	Biomass (mg/m^3)	s_A (38 kHz) (m^2/nmi^2)	s_A (200 kHz) (m^2/nmi^2)	Bongo (ind./m^3)	Van Dorn (ind./m^3)	Biomass (mg/m^3)
10	14	10	346	5500	0.0032	13	5	68	3700	0.0041	115	32	63	1600	0.0033
20	251	40	269	6900	0.0025	32	11	107	4450	0.0023	61	29	40	2300	0.0024
30	532	65	162	4050	0.0037	106	31	62	3850	0.0021	102	41	89	2550	0.0060
40	280	42	88	1950	0.0029	134	33	90	1650	0.0028	127	49	138	1550	0.0087
50	78	17	232	2700	0.0045	280	32	337	1650	0.0158	135	110	147	2200	0.0081
60	316	33	334	2400	0.0047	179	15	564	1750	0.0170	238	93	265	1700	0.0131

Depth	Sampling Site 2 (Night)									
	September					October				
	s_A (38 kHz) (m^2/nmi^2)	s_A (200 kHz) (m^2/nmi^2)	Bongo (ind./m^3)	Van Dorn (ind./m^3)	Biomass (mg/m^3)	s_A (38 kHz) (m^2/nmi^2)	s_A (200 kHz) (m^2/nmi^2)	Bongo (ind./m^3)	Van Dorn (ind./m^3)	Biomass (mg/m^3)
10	50	19	622	4100	0.0132	72	27	190	2700	0.0105
20	88	30	240	4800	0.0085	105	33	173	1000	0.0093
30	89	32	89	2150	0.0082	160	41	159	1750	0.0120
40	110	34	140	2000	0.0083	138	49	119	2600	0.0077
50	309	66	140	2300	0.0085	640	110	187	1950	0.0094
60	199	56	79	1750	0.0082	491	93	180	2600	0.0098

Appendix 5. *Histogram of prosome length distributions at Sampling Site 1 and 2 measured by the ZooScan system.*