

**Zooplankton diel vertical migration and distribution relative to Cross Seamount using  
75 kHz acoustic and net tow surveys.**

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## **Non-technical Summary**

Many seamounts are sites of high fish, bird, and mammal abundance compared to the biologically relatively sparse open ocean. Some seamounts, such as Cross Seamount, support economically important fish populations that are thought to feed on higher abundances of micronekton (actively swimming organisms ~2-20 cm in size) that in turn feed on zooplankton. Other studies have examined micronekton or phytoplankton, which are consumed by zooplankton. However, no studies in the seamount region near the Hawaiian Islands have included zooplankton in their analyses. This project attempts to quantify and explain differences in zooplankton distribution and abundance on the top and sides of Cross Seamount. Zooplankton were collected with nets at different depths during both day and night tows. Properties of the water column (temperature, salinity, and chlorophyll content) were also measured at these sites. Acoustics were used to collect data about currents around the seamount. The effects of seamounts on zooplankton movement and abundance were assessed by comparing on- and off-summit/seamount samples. Zooplankton were slightly less abundant on the seamount flanks compared to background levels found away from the seamount. Although total abundances of zooplankton on the flanks and top of the seamount seem comparable, densities of zooplankton differ by depth between locations and may provide higher concentrations of food for micronekton and other fish. Zooplankton data of this kind has not been collected before, at Cross Seamount and during this time of year. The results will help inform future biological studies around Hawaii and add to existing data on the influence of seamounts on the planktonic community.

## **Abstract**

Many seamounts are sites of high fish, bird, and mammal abundance compared to the oligotrophic open ocean. Some seamounts, such as Cross Seamount, support economically important fish populations that are thought to feed on micronekton (actively swimming organisms ~2-20 cm in size) that in turn feed on zooplankton. Here, I hypothesize that Cross Seamount zooplankton community assemblages will differ from background levels away from this submarine structure. Specifically, the seamount may alter zooplankton behavior, current dynamics, and predator distributions, which in turn may influence planktonic distributions and community composition. Here, I examine zooplankton distribution and abundance on the summit and flanks of Cross Seamount. I identified and enumerated zooplankton samples from depth-stratified vertical net tows conducted during 31 Dec 2010–1 January 2011. Although data was inconclusive due to net mesh size effects and small sample sizes, zooplankton were less abundant on the seamount compared to an off-seamount reference site, and summit abundances were comparable to those on the flank. However, differences in densities between depth-stratified flank and summit locations may still be significant in providing higher-density forage opportunities for micronekton and other fish. Identifying and understanding seamount zooplankton distribution patterns will help inform future biological studies around Hawaii and add to existing data on the influence of seamounts on the planktonic community.

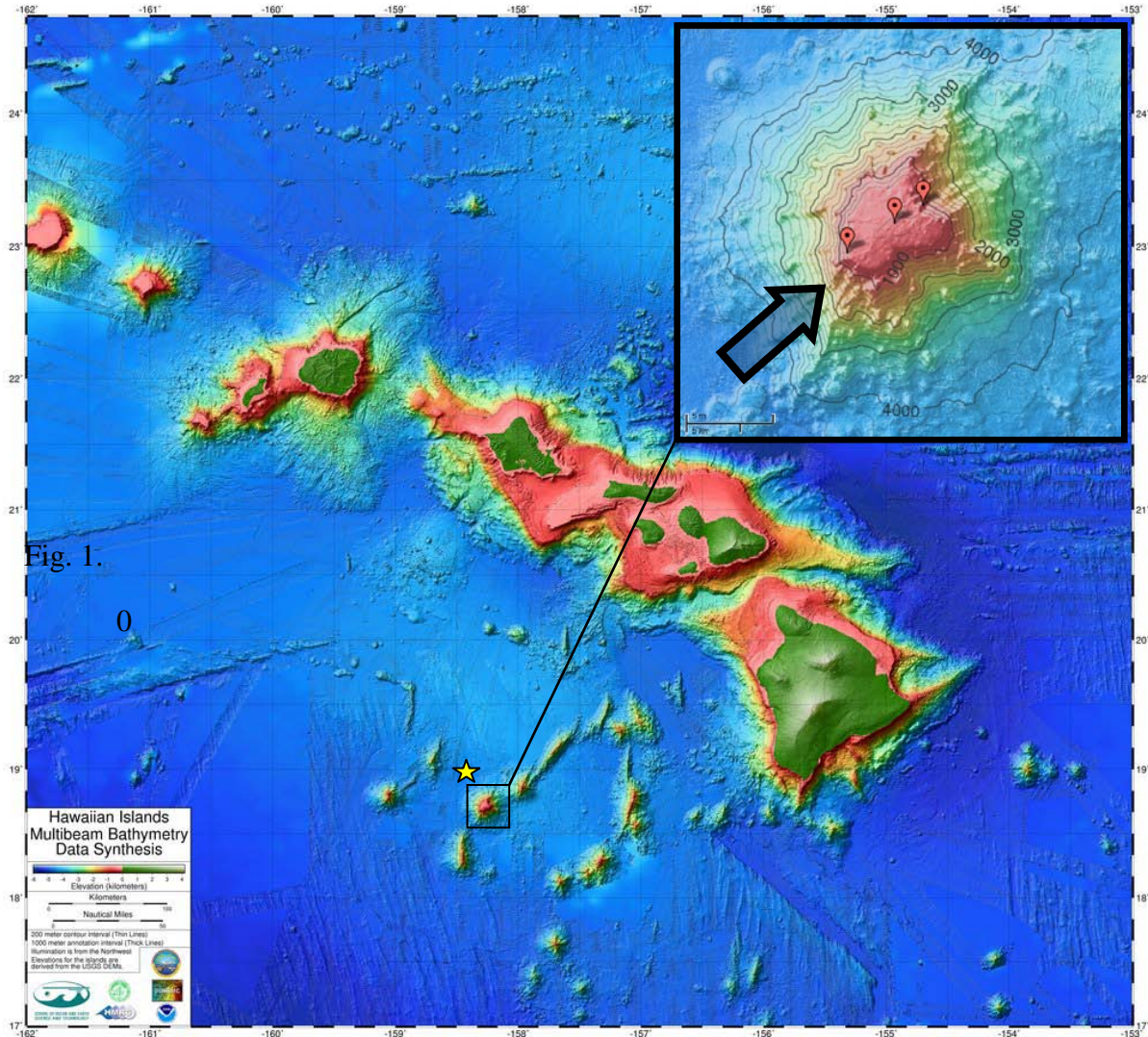


Fig. 1. Bathymetric map of Hawaii, including Cross Seamount study site (inset) and reference point (star). Seamount sampling locations (red pins) and direction of impinging surface flow (blue arrow) are indicated in the inset map.

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Seamounts are sites of high biological diversity and increased production relative to background levels away from these submarine mountains (Morato et al. 2010). Cross Seamount (~158 15'W, ~18 40'N) (Fig. 1), located southwest of the Hawaiian island chain, is one of many structures in the eastern Pacific that has been shown to provide foraging opportunities for beaked whales (Johnston et al. 2008), and to support economically important species such as bigeye tuna, *Thunnus obesus* (Musyl et al. 2003). These large predators feed on micronekton, such as myctophid fishes, which in turn feed on zooplankton. Previous studies have reported on prey aggregations and patchiness around the summit and slopes of similarly shallow seamounts. However, few include interactions of taxon-specific diel vertical migration and biophysical interactions. An understanding of this general interaction, and more specifically, variation in zooplankton behavior between the summit, slope, and regions surrounding a seamount can provide further insight into how large geological structures support biologically diverse food webs.

Traditional understanding of enhanced local productivity, known as the “seamount effect” (Dower and Mackas 1996) has focused primarily on local upwelling of nutrients, retention of primary production, and subsequent predation by larger secondary consumers and nekton (Genin 2004). More recent studies examine biological communities downstream and upstream of seamounts (“downstream” refers to areas downcurrent of the structure). These studies emphasize the importance of advected (non-localized) production and the phenomenon of a plankton “hole” immediately above the summit, which may reflect locally intense predation on zooplankton (Dower and Mackas 1996; De Forest and Drazen 2009). It was hypothesized that concentration of vertically migrating plankton above seamounts led to

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increased predation on the summit by seamount-associated organisms. The plankton “hole” resulted from the absence of consumed organisms from populations advected from the seamount area, leading to increased patchiness downstream the following day.

Variation between individual seamounts and the complexity of the mechanisms influencing zooplankton community assemblages necessitate process-oriented studies comparing multiple sites. Larger scale studies by Haury et al. (2000) and Martin and Christiansen (2009) reported day/night zooplankton distribution around seamounts off the coast of California and in the NE Atlantic, respectively. Both studies were part of large multi-year projects, with sampling designs that were informed by preliminary hydrographic and/or acoustic surveys. Haury et al. (2000) showed that increased copepod carcasses indicative of predation were found over two of three seamount summits with zooplankton gaps. Additionally, although results varied greatly, this study indicated that potential differences in community composition might have been influenced by taxon-specific strengths of vertical migration. Similarly, Martin and Christiansen (2009) indicated that although physical processes most likely dominate shallow seamount zooplankton distribution processes, larger organisms might actively avoid the seamount structure or be displaced by currents as they migrated strongly. They attributed the absence of small zooplankton <0.5 cm over the summit (170 m depth) of Seine Seamount to fish predation, an interpretation that was supported by planktivorous fish stomach content analysis. Few studies have similarly directly considered interactions of taxon-specific migration and biophysical interactions. An understanding of this interaction, and more specifically, how zooplankton behavior varies between the summit,

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slope, and regions surrounding a seamount can provide further insight into how large geological structures support biologically diverse food webs.

Interdisciplinary studies such as these allow for a more comprehensive understanding of the leading drivers of zooplankton community structure. However, given the complexity of these mechanisms, it is also important to identify circumstances where biological and/or physical processes dominate, and to directly address the potential for interactions between processes with similar spatiotemporal scales. An approach combining traditional physical and biological field sampling with a modeling component has the potential to fill crucial gaps in our understanding of seamount plankton dynamics. The conclusions of such a project could demonstrate the efficiency of an alternative approach to explore other paradigms in the field of fisheries-oceanography.

Given the patterns explained in previous research, the focus of this project will be guided by these questions:

1. Does biological abundance and distribution vary between on- and off-summit/seamount locations?
2. Do zooplankton community assemblages differ between on- and off-seamount locations, and are certain species found only in seamount vs pelagic environments?
3. Are these patterns explained by biological or physical mechanisms, or an interaction of these processes?

This project describes zooplankton temporal and spatial distribution on and around Cross Seamount, placing this data in the context of phytoplankton prey, nektonic predator, and

physical flow influences. How does the “seamount effect” interact with DVM and other biological processes to influence zooplankton abundance and distribution?

Although this winter zooplankton sampling attempt will be disadvantaged by 1) lack of preexisting zooplankton data in this region, during this season and 2) cruise time limitations and lack of high-frequency acoustic resources, any data collected will provide novel results and aid in the description of Cross Seamount zooplankton population abundance and distribution. There are relatively few zooplankton studies focusing on the regions around Hawaii, and most process-oriented projects have not sampled during the winter (Noble and Mullineaux 1989; De Forest and Drazen 2009). Lack of winter data is presumably a result of higher interest in spring and summer dynamics, and the relative ease of sampling during these seasons. However, detecting seasonal differences and characterizing variability is an important component of characterizing biological processes. Identifying the processes that influence the prey base of commercially and ecologically important fish and mammals will provide valuable information for ecological modelers and fisheries managers, informing predictions of ecosystem impacts of environmental variability and climate change.

## **Field and laboratory methods**

I conducted CTD (conductivity, temperature, depth) casts and vertical zooplankton tows from the R/V *Thomas G. Thompson* to collect biological and physical data at Cross Seamount (18° 40'N, 158° 15'W) and a reference point (18° 56'N, 158° 25'W) between 31 December 2010–2 January 2011. Current velocity data was collected using a hull-mounted Teledyne RD 75 kHz Ocean Surveyor ADCP (Acoustic Doppler Current Profiler). The ADCP

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survey transects spanned the summit and flanks of the seamount. These 4-hour surveys alternated with zooplankton tows collected along a NE-SE transect roughly parallel to current direction. I collected zooplankton with a 200 micron open/closing net towed vertically from 550-370/380, 370/380-150, 150-60, and 60-0 meters. Day and night samples were taken at the summit and upstream/downstream flanks of Cross seamount, and a reference point away from the seamount. A TSK and/or General Oceanics mechanical flowmeter attached to the top of the net recorded the volume of water sampled. The 200 micron net and associated flowmeters were lost after tow 14, and thereafter an open 333 micron ring net was used to collect the day-downstream and night-upstream samples, as well as the reference point sample (Table 1).

Table 1. Cross Seamount and reference point zooplankton tows.

Station	Date	Day/Night	Mesh Size (um)	Depth (m)	Latitude (N)	Longitude (W)
Summit	31-Dec	Day	200	380-150 150-60 60-0	18° 42.9'	158° 16.0'
	31-Dec	Night	200	380-150 150-60 60-0	18° 42.8'	158° 15.9'
Upstream	1-Jan	Day	200	550-370 370-150 150-60 60-0	18° 41.3'	158° 18.5'
	2-Jan	Night	333	550-0 150-0 60-0	18° 41.3'	158° 18.5'
Downstream	1-Jan	Day	333	550-0 150-0 60-0	18° 44.1'	158° 14.3'
	1-Jan	Night	200	550-370 370-150 150-60 60-0	18° 43.7'	158° 14.5'
Reference	2-Jan	Day	333	550-0	18° 56.5'	158° 25.2'

Zooplankton samples were preserved in 5% formalin and taken to the laboratory for analysis. In the laboratory, we used a Folsom plankton splitter to quantitatively subsample 1/16 or 1/32 of the total sample. A minimum of 400 individuals were counted and measured per sample with a dissecting microscope. I grouped individuals into general taxa such as chaetognath, pteropod, euphausiid, copepod, and siphonophore. I recorded the abundance by taxa ( $m^{-3}$ ), calculated species richness ( $r$ ) as the number of taxa in each sample, and analyzed counts for presence/absence of species by location.

## Results

### Total Abundance and Density

Between 333 micron mesh size samples, zooplankton were generally less abundant on the seamount compared to an off-seamount reference site although level of significance could not be determined (Fig. 2). Density and abundance results were lower at sites where the larger 333 micron mesh size net was used. However, locations sampled on the seamount had up to seven times the density of individuals/ $m^3$  (141.8 individuals/ $m^3$  on the summit at night) as

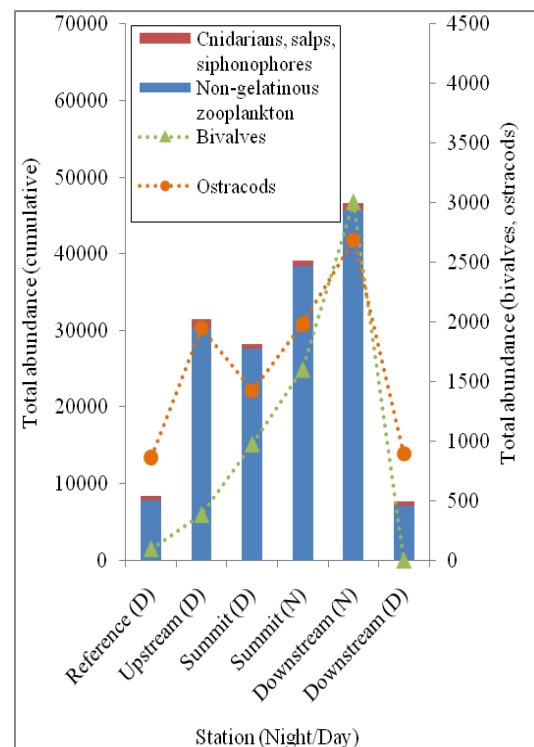


Fig. 2. Total abundance of all zooplankton (non-gelatinous and gelatinous), and abundance patterns of bivalves and ostracods.

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found at the reference site (18.6 individuals/m<sup>3</sup>), and species richness was also higher at the seamount. Using 200 micron mesh size samples, total abundance of zooplankton generally increased from upstream to downstream except for a decrease during the day at the summit (Fig. 2).

### **Abundance and trends by taxa**

The most abundant taxa at all stations were copepods, ostracods, and chaetognaths. Populations were composed of up to 85% copepods by number of individuals. Other major taxa included bivalves, siphonophores, gastropods, and larvaceans. Gastropods, some species of pteropods and shrimps, polychaetes, and tunicates were found at the seamount and not at the reference site. However, these individuals did not make up a great proportion of the population by number of individuals.

Copepods, ostracods, chaetognaths, and larvaceans displayed similar trends of abundance between upstream, summit, and downstream sites (see Fig. 2 for ostracod trend example). With these taxa, upstream and summit abundances were similar, but day summit abundances were slightly lower. In contrast, euphausiids, bivalves, chaetognaths, and shrimp increased from upstream to summit (day and night) to downstream sites.

### **Depth-stratified tows**

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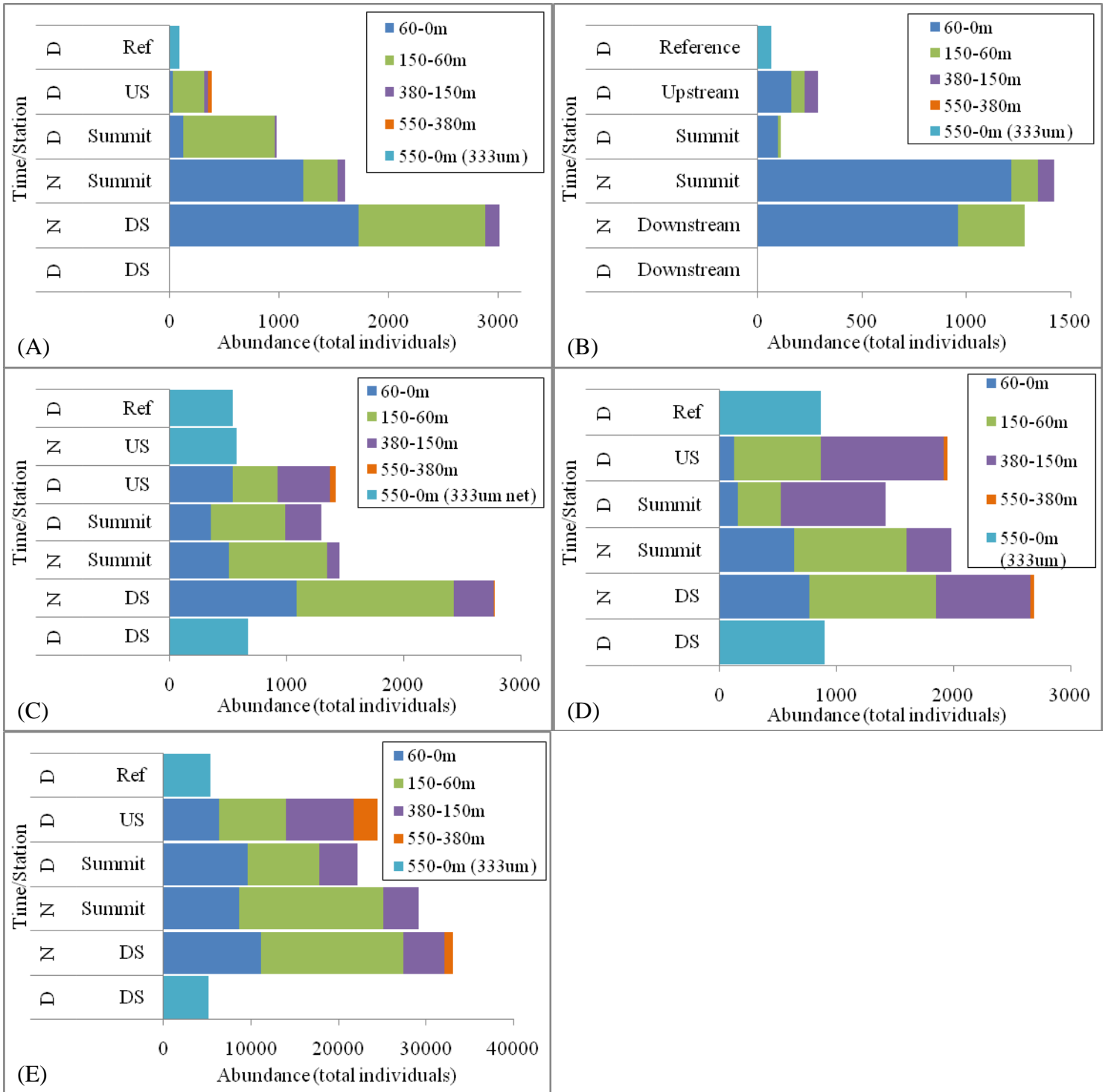
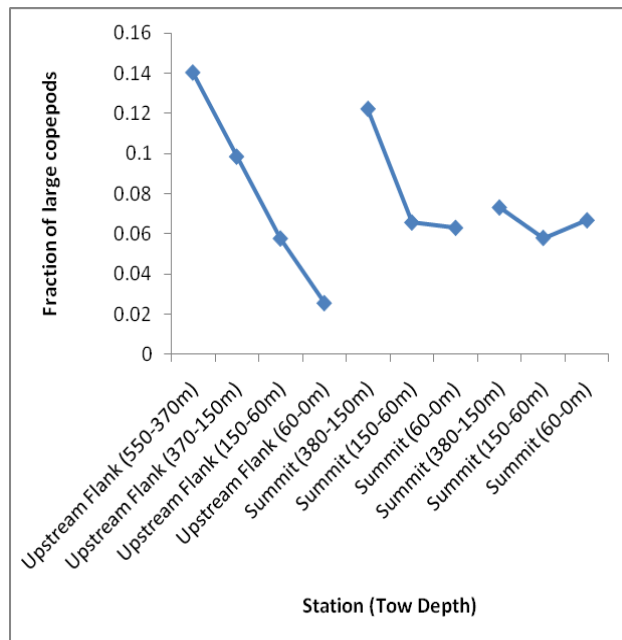


Fig. 3. Depth-stratified total abundances for bivalves (A), gastropods (B), chaetognaths (C), ostracods (D), and copepods (E) by station (Ref=reference, US=upstream, DS=downstream)

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and time (D=day, N=night). Green denotes depth bin of the chlorophyll max while orange signifies deepest depth bin, below maximum summit depth (>380m).

Copepods and chaetognaths were similarly abundant from 0-550m on the flank and 0-380m (summit depth) over the summit using data from only the 202 micron net. However, depth-stratified tows showed that zooplankton were most abundant in the upper 150 meters. The chlorophyll maximum was similarly consistently found within 60-150m below the surface.



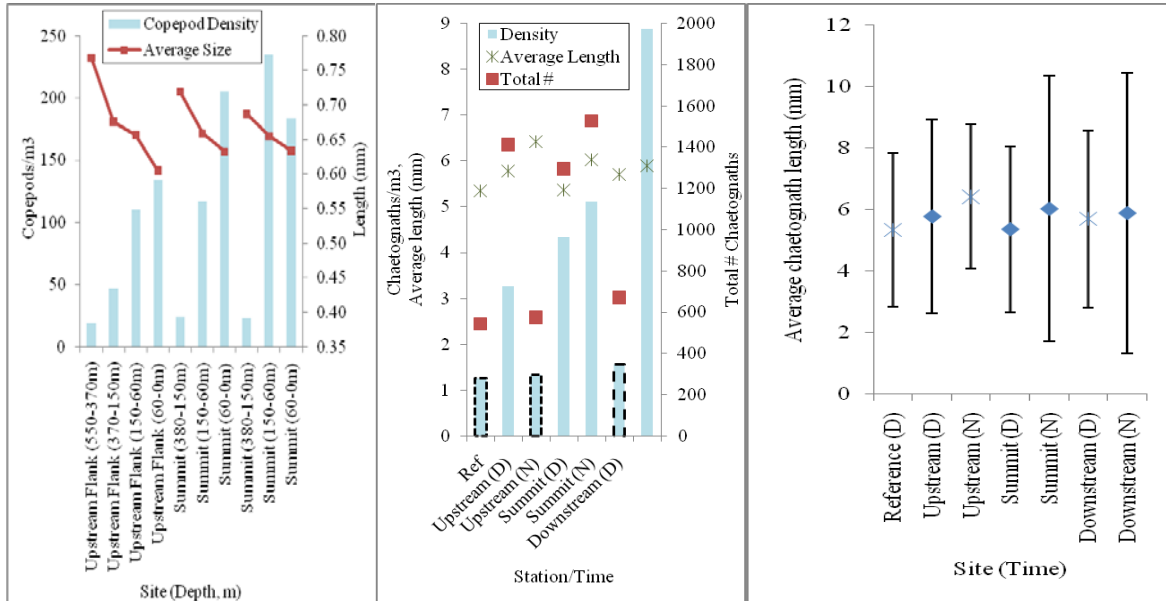
Chaetognaths and copepods displayed similar patterns in vertically integrated density across sampled stations and times. However, depth-stratified patterns differed. Comparing upstream day to summit day and night samples, copepods were concentrated in the upper 60m, except on the summit at night, where populations were the most dense in the 60-150m depth bin. The fraction of large

copepods on the summit decreased slightly during the day in the upper 60m. A larger proportion of copepods >1mm were found on the summit at night in the upper 60m.

Chaetognaths were concentrated within the upper 60m only during the day on the upstream flank. On the summit, they were most concentrated between 60-150m. In comparing size, larger copepods were consistently found at depth. The fraction of large copepods decreased consistently with depth on the flank. On the summit, this trend was less apparent.

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Data for chaetognath trends came from samples sizes as small as  $n=7$ , and patterns were less defined compared to copepod trends. Average chaetognath length was lowest at night on the summit, but chaetognath density in the upper 150m was greater than daytime densities.



## Discussion

The high densities of plankton found within the surface layers may reflect vertical positioning of chaetognaths and copepods to maximize predation opportunities. Vertical migration of ostracods and chaetognaths reflect results of previous subtropical diel vertical migration studies (Steinberg et al. 2008). The difference in chaetognath and copepod densities in the first two depth bins may reflect behavior to balance the tradeoff of feeding and predation, or actual population reduction by seamount predators such as micronekton. The absence of larger copepods on the summit could reflect avoidance of the structure by strong swimmers or advection of these organisms around the seamount, at 550-370m depth. Alternatively, the change in average size and fraction of large copepods in the population could indicate that vertical motion of water passing over the seamount is great enough

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supply the summit, at 380m, with smaller-bodied copepods that display depth-retaining behavior. This combination of behavior and advection could theoretically concentrate copepods into denser layers.

Source populations of certain taxa, like bivalves and gastropods, might be located on the seamount. Differences in day and night abundances of these organisms on the summit might reflect changes in current direction and speed if source populations are not distributed evenly across the seamount substrate. In this analysis, foraminifera were not considered in total abundances since it is difficult to discern live from dead individuals. Deep tows contained numerous individuals (up to 10,000 in the 550-380m upstream flank tow and 500 in the 380-150m night summit tow). cursory examination of sediment grabs from the flanks of the seamount revealed foraminiferal sands, which indicate the possibility of a sediment fan around the seamount. In addition, the high abundance and densities of organisms on the downstream flank may be the result of converging currents (Z. Mazlan, personal communication) directed towards the indent in the seamount summit.

It is interesting to note that differences in abundance, density, and size distribution of various taxa could lend insight into seamount prey-concentrating processes. For example, the differences between chaetognaths and copepods could result from differential swimming strength. If predation is insignificant, other processes like behavior and advection might dominate. Additionally, the circulation around the seamount has not been fully explored and assessed. Quantifying current speed and determining direction and variability of water movement would assist in analysis of these processes and their interactions. For example, if currents carry organisms around the seamount instead of up and over the summit, the

reduction in copepod abundance below the summit depth could indicate significant flank-associated predation.

The apparent high abundance of zooplankton on the summit as compared to the flank may be an artifact of mesh size. However, interpreted literally, the data suggests that there are more zooplankton over the summit than the upstream flank. This may indicate that predation is high on the flanks, where micronekton and larger fish have been known to feed, and where they have been found in higher densities. If circulation in the top 200 meters followed a fairly consistent northeasterly direction, and if currents slow and begin to rotate at depth (Z. Mazlan, pers. comm.), it is possible that zooplankton are concentrated on the summit, advected over the mountain, and supply the flanks at depth where currents slow and micronekton are found in higher abundances. In addition, if chaetognaths exhibited migration to depth downstream of the seamount, it is possible that they might be retained in this area of higher copepod prey abundance, and with a growth rate of approximately .3mm/day, chaetognath growth and biomass could substantially increase, and predation on copepods could have a significant effect on smaller-bodied copepod abundance.

## **Conclusions**

Although data was inconclusive due to net mesh size effects and small sample sizes, zooplankton were less abundant on the seamount compared to an off-seamount reference site, and summit abundances were comparable to those on the flank. However, differences in densities between depth-stratified flank and summit locations may still be significant in providing higher-density forage opportunities for micronekton and other fish. Vertical

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migration and differences between summit and flank locations were apparent in taxa like bivalves. Other taxa displayed more complex patterns that could be explained by depth-stratified data while others showed surprising results that were not supported by this analysis. For example, increases in small copepod abundance on the summit suggest these organisms were not directly advected from upstream of the seamount as hypothesized. Further research should consider horizontal advection of zooplankton and design sampling plans specific to seamount bathymetry.

**Table 3.** Rates and ratios used in analysis.

<b>Mechanism</b>	<b>Parameter</b>	<b>Numerical description</b>	<b>Ratio (time)</b>
Behavior	Swimming speed (V)	.0297 m/sec (Mauchline et al. 1998)	D/V = 3333 sec. ~1 hour
	Photic zone depth (D)	100 m (Cortes et al. 2001)	
Advection	Length (L) “seamount effect”	11 km (Wessel and Keating 1994)	L/U ~55 hours
	Advection rate (U)	5.2 cm/sec. (Noble and Mullineaux 1989)	

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