

Cross Seamount Zooplankton

The Abundance and Distribution of Small Zooplankton near Cross Seamount

James Peck
School of Oceanography, Box 357940
University of Washington
Seattle, WA 98195-7940
Phone: (206) 543-5060
jap24@u.washington.edu

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Summary

Seamounts are isolated shallow regions of the oceans formed by volcanoes. Seamounts have been found to support unusually large numbers of fish. It is possible that fish on seamounts are fed on small animals called zooplankton that drift over seamounts with the currents. In most of the surface ocean, fish hunt using their eyes, and to avoid being eaten some species of zooplankton swim down during the daytime until it is too dark to be seen, then return to the surface to feed at night. The shallow summit of a seamount could prevent zooplankton from descending far enough to avoid fish, giving fish an unusually rich food supply. In this study, I examine the distribution and abundance of zooplankton over, near and far from Cross Seamount. I captured small zooplankton with nets to examine under a microscope. I hypothesized that the small zooplankton would be unaffected by the seamount because their daytime depths are not shallow enough for them to reach the seamount summit, while larger migrating organisms would be less abundant. Since I could not study larger organisms myself, I relied on past research that had taken place at Cross seamount that had found a strong reduction in the populations of organisms that migrate to a deep daytime depth over the seamount. The small zooplankton that I studied seem to be generally unaffected by the presence of the seamount, supporting my hypothesis.

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Abstract

I examined the abundance, diversity and size distribution of the zooplankton population of Cross Seamount to determine if it was different from a reference site over deep ocean, and to try to determine which mechanisms contribute to any differences. In particular, I tested the hypothesis that the shallowness of a seamount's summit could interfere with diel vertical migration, and as a result increase the mortality of zooplankton that customarily migrate deeper than the seamount summit. To do this, I compared the effects of the Cross Seamount on small zooplankton, which do not migrate as deep as the seamount summit, with the results of a past micronekton study at Cross seamount, which focused on organisms that usually migrate deeper than the seamount's 380m summit. I collected small zooplankton with net tows using a 1m diameter closing net with a 200 μ m mesh, and a 1m open net with a 333 μ m mesh. The total number of zooplankton per m³ varied between 31 at the reference station and 365 in the top 60m downstream of the seamount during the night. The zooplankton populations were made up mostly of copepods, but I recorded more than 20 other taxa. While the previous study on Cross seamount had found that strongly migratory micronekton grew less numerous closer to the seamount summit, the small zooplankton population was largely unaffected by proximity to the seamount. Only the zooplankton from the deepest part of the water column over the summit had a definitively reduced abundance compared with the flanks. This seems to support the theory that organisms that customarily migrate deeper than the summit of the seamount are experiencing increased predation at the seamount while organisms that do not migrate that deep do not experience increased predation.

Introduction

Zooplankton populations above seamounts are different from nearby open ocean populations in

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abundance (Martin and Christiansen 2009) and diversity (Dower and Mackas 1996). There are two primary hypotheses about the mechanisms causing these differences between zooplankton populations over seamounts and away from seamounts. One mechanism is that transport by currents could lower the abundance of vertically migrating zooplankton. This could happen when there is a phenomenon such as a Taylor cap over a seamount, which causes most particles over the seamount to be retained. A model by Beckmann and Mohn (2002) demonstrated that vertically migrating particles would not be retained as strongly as other particles. Selective loss of vertically migrating zooplankton could explain reduced zooplankton abundance and different community composition over seamounts. Alternately, if zooplankton that maintain a depth below the seamount summit are swept past it instead of over it by prevailing currents, then advection over the seamount during the day would bring in water with very few migrators. This would cause a reduction in the relative abundance of migrating zooplankton (Genin, Haury and Greenblatt 1988). The second possible mechanism is that zooplankton community composition is changed over seamounts due to predation. In this case, high concentration of fish over seamounts preferentially eat some types of zooplankton but not others, causing measurable changes to zooplankton communities as they pass over seamounts.

Zooplankton diel vertical migration could be an important factor in how seamount fish feed. Zooplankton, including copepods, are among the primary prey animals consumed by benthopelagic fish at seamounts (Christiansen, Martin and Hirsch 2009). It is possible that the large fish populations at seamounts are sustained by zooplankton carried over the seamounts by currents, as more zooplankton biomass passes above the seamount than could be produced over it (Koslow 1997). Normally, diel vertical migration allows zooplankton such as euphausiids and copepods to avoid predators as they descend near dawn to depths with too little light for predators to see (DeRobertis et al. 2000). However, when migrating zooplankton descend over a seamount, if the seamount is shallow compared

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with the migrator's preferred depth, then the migrator could be forced to remain in relatively well-lit water with large concentrations of zooplanktivorous fish (Genin et al. 1988; De Forest and Drazen 2009). This steady supply of migrating zooplankton would be carried over the seamount by currents at night and could be a major component of the diet of seamount fish (Genin, Haury and Greenblatt 1988).

Martin and Christiansen (2009) speculated that other factors could also influence zooplankton populations over seamounts. It is possible migrating zooplankton and micronekton could actively avoid seamounts by attempting to swim around them due to the shallow depth of the top of the seamount compared to the depths to which these animals migrate. Also, zooplankton might change their behavior when they are over a seamount. For example, Genin, Haury and Greenblatt (1988) found that euphausiids over a shallow seamount during the day remained dozens of meters above the summit of the seamount, even though the seamount summit was shallower than their normal daytime depth.

Past research has discovered that zooplankton community composition and overall abundance differs over seamounts compared with nearby deep ocean sites. Dower and Mackas (1996) found that zooplankton community composition around Cobb seamount was different from the surrounding waters, but did not find any differences in absolute abundance. Genin et al. (1988) studied euphausiids at a shallow seamount near California using acoustics and net tows. They noted that euphausiids were much less abundant over the seamount than they were in surrounding regions. They caught fish from the seamount at several locations and times, and found that fish caught over the seamount shortly after dawn had more euphausiids in their stomachs than fish caught at other times. This suggests vertical migration may have provided the seamount fish population with a more concentrated food source than in deeper waters. De Forest and Drazen (2009) studied euphausiids at Cross seamount using trawls. They found that euphausiids were generally absent over the seamount, and speculated that it might be

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because the seamount summit is shallower than the euphausiid vertical migration range, causing them to be carried past the seamount by currents during the day, but could not rule out predation.

An implication of De Forest and Drazen's (2009) findings is that zooplankton will be strongly affected only by seamounts that project higher than their daytime depths. Because small zooplankton descend to shallower depths than large zooplankton (DeRobertis et al. 2000), small zooplankton will not be as strongly affected by seamounts as large zooplankton. This study investigates the abundance and distribution of small zooplankton near Cross seamount, in order to compare small zooplankton distributions with the large migrator distributions found by De Forest and Drazen. Large migrating organisms tend to have a large migration range, for example euphausiids tend to migrate to depths between 300m and 500m during the day (Binton 1967). Cross seamount has a summit depth shallower than 400m (Noble and Mullineaux 1989; De Forest and Drazen 2009), so it should be shallow enough to interfere with euphausiid migration. Smaller zooplankton found in the region tend to remain shallower than 300m during the day, though there are exceptions (Steinberg et al. 2008), so for the most part the small zooplankton population should be unaffected by Cross seamount. This study tests De Forest and Drazen's hypothesis that interference in vertical migration by the shallowness of a seamount's summit affects zooplankton mortality by comparing the effects of the seamount on micronekton and small zooplankton.

Seamount zooplankton populations are important because they sustain seamount fish populations. Seamounts often host important commercial fisheries, as high abundances of valuable fish often inhabit the zone above the summit (Koslow 1997). However, commercial fishing at many seamounts has been unsustainable and has damaged local ecosystems (Pitcher 2010). Koslow (1997) found that seamount fisheries that were not actively researched and managed tended to collapse within 10 years. Determining the relationships between fish and zooplankton populations will help provide

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the necessary understanding to establish ecosystem-friendly sustainable fisheries at seamounts.

Methods

From 31 December 2010 to 2 January 2011, the *R/V Thomas G. Thompson* stopped at three sites over Cross Seamount at both day and night, and at a reference site about 30km from the seamount during the day. The three seamount sites were oriented so that one was roughly downstream of the seamount, one was over the summit, and one was upstream of the seamount. I used net tows with 1m diameter nets to collect zooplankton samples at various depths for each site. Most samples were collected with a 200 μ m mesh closing net, but this net was lost during the downstream day sampling and was replaced with a 333 μ m mesh open net (Table 1). All samples were fixed with formalin. Later, I split the zooplankton samples and examined subsamples from all of the 200 micron mesh samples and two of the 333 micron mesh samples under a dissecting microscope. I recorded the body length of each individual, and categorized them by taxa.

Copepods with long antenna I classified as calanoid, and copepods with short antennae I classified as cyclopid, which might not be accurate because of the presence of members of the cyclopid genus *Oithona*, which has long antennae. After the first three stations, I started labeling the copepods with long antennae and long tails separately as *Oithona*, but for my size distribution calculations I put *Oithona* and calanoid copepods in the same category.

Other data were also collected at Cross Seamount. At the upstream night station, a zooplankton imager was lowered to 50m depth to observe large zooplankton in situ, however that data has not been analyzed due to time limitations. Also, sediment samples were collected from several locations over the seamount, and sediment from one of them was examined using microscopy qualitatively evaluate its composition. The *R/V Thompson's* ADCP system recorded current direction and magnitude.

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Results

The seamount depth-stratified tows from both day and night had population densities decreasing with increasing depth from 250 to 365 individuals per cubic meter in the top 60m to 32 or fewer individuals per cubic meter in the bottom layers. The zooplankton population consisted primarily of copepods, but with many other taxa present (Appendix 1.; Appendix 2; Appendix 3; Appendix 4; Appendix 5). The reference point had only 18.6 individuals per cubic meter, and it had much lower concentrations of some zooplankton taxa that were abundant over the seamount, such as the bivalves (Appendix 3). The distribution from upstream day had a pattern similar to the summit, except that zooplankton were generally less numerous upstream, and the bottom layer had a high zooplankton population due to the presence of an unusually large number of Foraminifera in the sample (Appendix 4). The downstream night tows had exceptionally high zooplankton abundance in the top two depth bins, and the lowest concentration in its deepest depth bin (Appendix 5).

The measurements of zooplankton show that the copepods captured by the 200 micron mesh net generally ranged in size from 0.3mm up to 2-3mm in length (Fig. 1; Fig. 2). Kruskal-Wallis comparing the copepod size distributions of the upstream day station with the summit day station found only one significantly different median size: cyclopoids were generally larger upstream than downstream in the 150-60m tows (Table 2). Most other taxa either stayed within a narrow size range, such as bivalves which were consistently between 0.3mm and 0.6mm, or they varied widely without a detectable pattern.

Discussion

Zooplankton were more abundant over the seamount summit than at the reference station

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(Appendix 3). It is possible that this is the result of advection working in an unexpected way on small zooplankton, or, if larger zooplankton such as euphausiids are being advected away or eaten at the summit, then the lack of predators for small zooplankton could allow their populations to grow large relative to the reference station. However, the most likely explanation for the large differences between the summit and the reference station is an artifact due to the difference in net mesh sizes. The net used at the reference station had a coarser mesh than the one used at the summit, and this would have allowed more individuals to escape the net at the reference station. The size distribution data for individuals at the summit compared to that for the reference station shows that only larger organisms were recorded at the reference station. For example, the smallest bivalves recorded at the reference station had a shell diameter of 0.5mm, while the most common bivalves at the seamount stations had shell sizes between 0.3mm and 0.4mm. As a result, it appears likely that the difference in the density of individuals recorded is the result of small organisms escaping from the net used at the reference station.

Further, the downstream day net tow through the whole water column performed using the 333 micron net had a comparable total abundance to the reference point, but a far lower total abundance compared with the total abundance for the whole water column calculated from the 200 micron net tows at the same site (Appendix 3). The differences between total abundance in the water column at the downstream site between times could be the result of patchiness, but given the similarity of the two tows using 333 micron nets, it is probably due to the differences in mesh sizes.

Steinberg, Cope, Wilson, and Kobari (2008) had previously found that waters at the ALOHA station near Hawaii were dominated by copepods and also contained significant numbers of salps, chaetognaths, ostracods, larvaceans, polychaetes, shrimp, amphipods, pteropods, heteropods, and euphausiids. All of these taxa except for heteropods were present in the samples taken at Cross.

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However, the Cross samples also contained a variety of bivalves, when no bivalves were recorded by Steinberg, Cope, Wilson, and Kobari. At some locations, bivalves made up a significant portion of the zooplankton population. For example, in the downstream night surface tow, bivalves made up more than 10% of the total population (Appendix 5). This difference could be due to this bivalve taxon living only near Cross, or it could be because of the difference net mesh size used in the previous study; they used a 335 micron multiple opening and closing net. Of the samples from Cross taken with a 333 micron mesh net, only the reference station contained any bivalves, and there the abundance of bivalves in the sample was far lower than in most of the 200 micron mesh samples. Due to either net differences or regional differences, the population at Cross is different from the ALOHA station.

Total zooplankton abundance seems to remain the same or even increase from upstream of the seamount to downstream. The deep tows at each station were designed to be as close to the seafloor as was feasible, so as a result the weighted average of the total abundances for all depth bins at a station should be equal to the total abundance in the water column at that station. Looking at the total abundances in the water column as a whole, the upstream day samples have 97.0 individuals m^{-3} ; however, a significant portion of the measured zooplankton population at the upstream station was made up of foraminifera (Appendix 4). A microscopic examination of a sediment sample taken at Cross seamount reveals that the sediments there contain significant numbers of dead foraminifera. The *R/V Thompson's* ADCP system revealed that the deep currents over Cross seamount were not always consistent with the current direction higher in the water column, and in some places the deep current moved in the opposite direction of currents from intermediate and shallow depths. It is possible that the foraminifera recorded in the deepest upstream tow were dead foraminifera from sediments mobilized by the currents. Excluding foraminifera from the deep tow at the upstream station reduces its measured total abundance to 75.1 individuals m^{-3} .

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The abundances in the whole water column at the summit vary widely. The summit samples from the day has 96.1 individuals m^{-3} , and the summit during the night has 133.5 individuals m^{-3} (Appendix 1). This difference could be due to patchiness of the zooplankton population over the seamount, or it could be due to errors while splitting the samples into subsamples for counting. The taxa with the largest magnitude difference between day and night included shelled zooplankton such as gastropods, bivalves and foraminifera (Fig. 1). Since I split the day samples first, when I was less experienced, and those samples had fewer shelled organisms, it is possible that some of the variation between day and night is a result of more of the shelled organisms from the day samples being destroyed in the splitting process. However, the differences in shelled organisms cannot account for all the differences between summit day and night. There were also significant differences in the abundance of copepods between day and night (Fig. 2), which might also be due to errors in splitting if I produced uneven subsamples, or again it could be due to patchiness in the zooplankton distribution. It is not clear if the differences between day and night are representative of the amount of variation at sites around the seamount, or if those differences are largely due to errors in splitting. In any case, the total zooplankton abundance at the summit is either not significantly less than the total abundance at the upstream flank, or the range of variation of zooplankton abundance at the summit includes the value for upstream flank. Looking at the individual depth bins, each depth bin at the summit during the day hosted a denser zooplankton population than the equivalent bin from upstream day, with the exception of the 380-150m depth range, where the summit had a reduced population of major taxa including all varieties of copepods and ostracods compared with upstream. The summit abundance of zooplankton does not appear to be significantly lower than that of the upstream flank, except for the deepest depth bin at the summit, and for most of the water column it appears to have higher zooplankton densities than upstream. The fact that the deepest depth bin at the summit has reduced

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abundance of zooplankton compared with upstream could indicate that the small zooplankton that are accustomed to spending the day at depths near that of the summit are experiencing the same phenomenon that causes the reduced micronekton abundances over the summit of Cross discovered by De Forest and Drazen (2009). This fits with the hypothesis of the seamount reducing the abundance of those species that normally migrate deeper than the summit depth.

The more reliable 200 micron net mesh data for the downstream flank had a total abundance of 108.4 individuals m^{-3} (Appendix 3), which falls between the values from the summit. It is an increase from the recorded upstream value, but if the variance between the total abundance of the summit tows shows the normal amount of variance that can be expected at a given site then this difference between upstream and downstream might not be significant. Since the downstream flank total abundance is between the summit day and night total abundances, there is not a significant difference between the summit and the downstream flank.

In terms of total abundance of zooplankton in the entire water column, there is no significant difference between the three stations near the seamount. This could be due to the fact that the stations were only about 5 km apart, so any processes affecting one station might be affecting all of them. Alternately, it could be due to the small sample size: since there was only one set of 200 micron mesh tows from upstream and downstream and two from the summit, it is difficult to judge what the variation due to patchiness is, and the only estimate for the range in values caused by patchiness comes from the sets of summit tows. If one set of summit tows was skewed for some reason, it could cause the appearance of more variation due to patchiness than actually exists, potentially causing results that are significant to appear insignificant. Another possibility is that there is genuinely no significant difference between the total abundance of small zooplankton across the seamount. This last possibility would support De Forest and Drazen's (2009) theory that zooplankton are more vulnerable to predation

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at seamounts if they normally migrate below the depth of the seamount summit. Of the zooplankton observed, only harpacticoid copepods (Steinberg et al. 2008) and the larger crustaceans (Binton 1967) tend to migrate deeper than the summit depth of about 400m during the day. Most of the small zooplankton taxa quantified here do not tend to migrate below the summit depth, so they should not be affected by the seamount.

The size distribution of copepods at the daytime upstream and summit stations showed unclear results. For both calanoid and cyclopoid copepods, the upstream station had a greater density of copepods in the 380-150m depth range. Strangely, the density of copepods over the summit from 380-150m was close to the density of copepods on the upstream flank from 550-380m (Fig. 3A; Fig. 4A). The low abundance of copepods in the deepest bin of the summit compared to the same depth bin upstream could indicate that copepod species which normally stay deeper than the seamount summit during the day are experiencing increased predation, as hypothesized by De Forest and Drazen (2009). The summit and upstream flank had roughly equal numbers of copepods in the 150-60m depth range, but the average size of calanoids was higher over the summit (Fig. 3B), while the average size of cyclopoids was higher at the upstream flank (Fig. 4B). In the shallowest depth range, from 60-0m, both types of copepod were most abundant at the summit, and this is most apparent with the cyclopoids (Fig. 3C; Fig. 4C). The results of Kruskal-Wallis tests to see if the median values for copepod sizes differ between equivalent depth ranges from the summit and the upstream flank do not reveal any significant results, except for the cyclopoid population from 150-60m (Table 2). The fact that the median sizes of copepods were mostly the same between the upstream flank and the summit is further evidence that visually-oriented predators are not having a strong effect on the small zooplankton population.

More research is necessary to understand the processes at seamounts that affect zooplankton.

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The data from Cross seamount is compatible with the hypothesis that organisms that normally migrate deeper than the seamount's summit are affected more strongly by the seamount than organisms that do not migrate below the summit depth. The fact that the deepest depth ranges over the summit had reduced abundances of zooplankton compared with both upstream and downstream sites at the same depth implies that the zooplankton in the deepest region of the seamount could be experiencing the same process that caused diminished micronekton abundance over Cross seamount (De Forest and Drazen 2009). While the results are consistent with seamount predators selectively consuming vertical migrators that normally spend the day below the summit depth, they cannot rule out the possibility of changes in zooplankton abundance due to advection. Additional research should focus on the effects of the currents around seamounts on migrating zooplankton, and on the behavior of seamount predators to see if they maneuver to take advantage of unlucky migrators.

Conclusions

The distribution of small zooplankton near Cross seamount is consistent with only the taxa which migrate below the depth of the summit experiencing strong effects due to the seamount. Generally, small zooplankton are no less abundant over the seamount summit than upstream or downstream. Only at the deepest depths are small zooplankton less abundant over the summit than upstream and downstream, indicating that only those species that normally live in depths comparable to the depth of the summit are strongly affected by the seamount.

Combined with the findings of De Forest and Drazen (2009) that Cross seamount had a reduced population of micronekton that migrated below the depth of the summit, this supports the hypothesis of that the seamount mostly has an effect on zooplankton that normally migrate beneath the depth of the summit. Additional research is needed to determine if the difference is due primarily to predation or to

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advection.

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Table 1. Net mesh sizes, depth ranges sampled, and the coordinates of each station.

| Station | Time of Day | Mesh Size | Depth Ranges (m) | Latitude (N) | Longitude (W) |
|------------|-------------|-----------|--------------------------------------|--------------|---------------|
| Summit | Day | 200 | 380-150 150-60 60-0 | 18° 42.9' | 158° 16.0' |
| | Night | 200 | 380-150 150-60 60-0 | 18° 42.8' | 158° 15.9' |
| Upstream | Day | 200 | 550-380 380-150 150-60 60-0 | 18° 41.3' | 158° 18.5' |
| | Night | 333 | 550-0* 150-0* 60-0* | 18° 41.3' | 158° 18.5' |
| Downstream | Day | 333 | 550-0 150-0* 60-0* | 18° 44.1' | 158° 14.3' |
| | Night | 200 | 550-370 370-150 150-60 60-0 | 18° 43.7' | 158° 14.5' |
| Reference | Day | 333 | 550-0 | 18° 56.5' | 158° 25.2' |

* Sample collected but not counted

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Table 2. The results of a series of kruskal-wallis non-parametric tests comparing the results of upstream day and summit day copepod size distributions. The p-values greater than 0.05 are assumed to be not significant.

| Test | p-value | Summit Mean (mm) | Summit Median (mm) | Upstream Mean (mm) | Upstream Median (mm) |
|------------------------|---------|------------------|--------------------|--------------------|----------------------|
| Calanoids at 380-150m | 0.1125 | 0.78 | 0.7 | 0.74 | 0.6 |
| Calanoids at 150-60m | 0.1501 | 0.73 | 0.6 | 0.69 | 0.6 |
| Calanoids at 60-0m | 0.4496 | 0.66 | 0.6 | 0.6 | 0.6 |
| Cyclopoids at 380-150m | 0.5485 | 0.61 | 0.5 | 0.57 | 0.55 |
| Cyclopoids at 150-60m | 0.0197 | 0.53 | 0.5 | 0.57 | 0.5 |
| Cyclopoids at 60-0m | 0.8325 | 0.55 | 0.5 | 0.54 | 0.5 |

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Fig. 1. The abundances of the shelled taxa at the summit that vary the most between night and day. The abundances are over the entire depth range of the summit, calculated from a weighted average of the depth stratified data.

Fig. 2. The abundances of the major groups of copepods recorded at the summit in the day and night. Oithona and calanoid were combined into a single category because they were not counted separately for most of the summit day samples.

Fig. 3. The size distributions of calanoid copepods at the daytime stations upstream and over the summit from A) the depth bins deeper than 150m, B) the depth bins from 150-60m, and C) the depth bins from 60-0m.

Fig. 4. The size distributions of cyclopoid copepods at the daytime stations upstream and over the summit from A) the depth bins deeper than 150m, B) the depth bins from 150-60m, and C) the depth bins from 60-0m.

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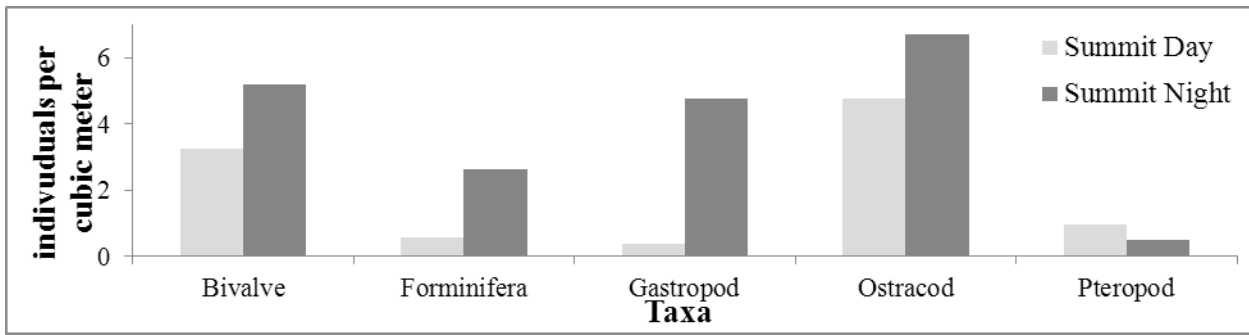


Fig. 1.

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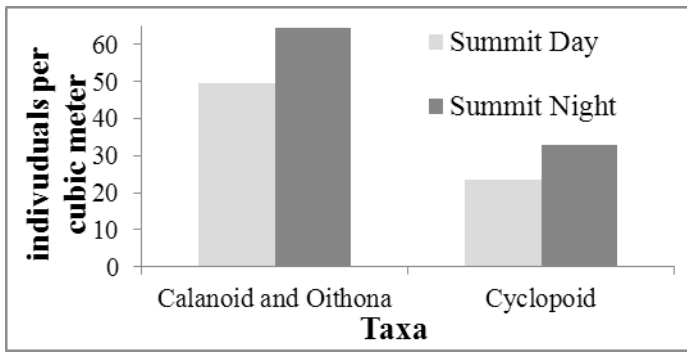


Fig. 2.

Cross Seamount Zooplankton

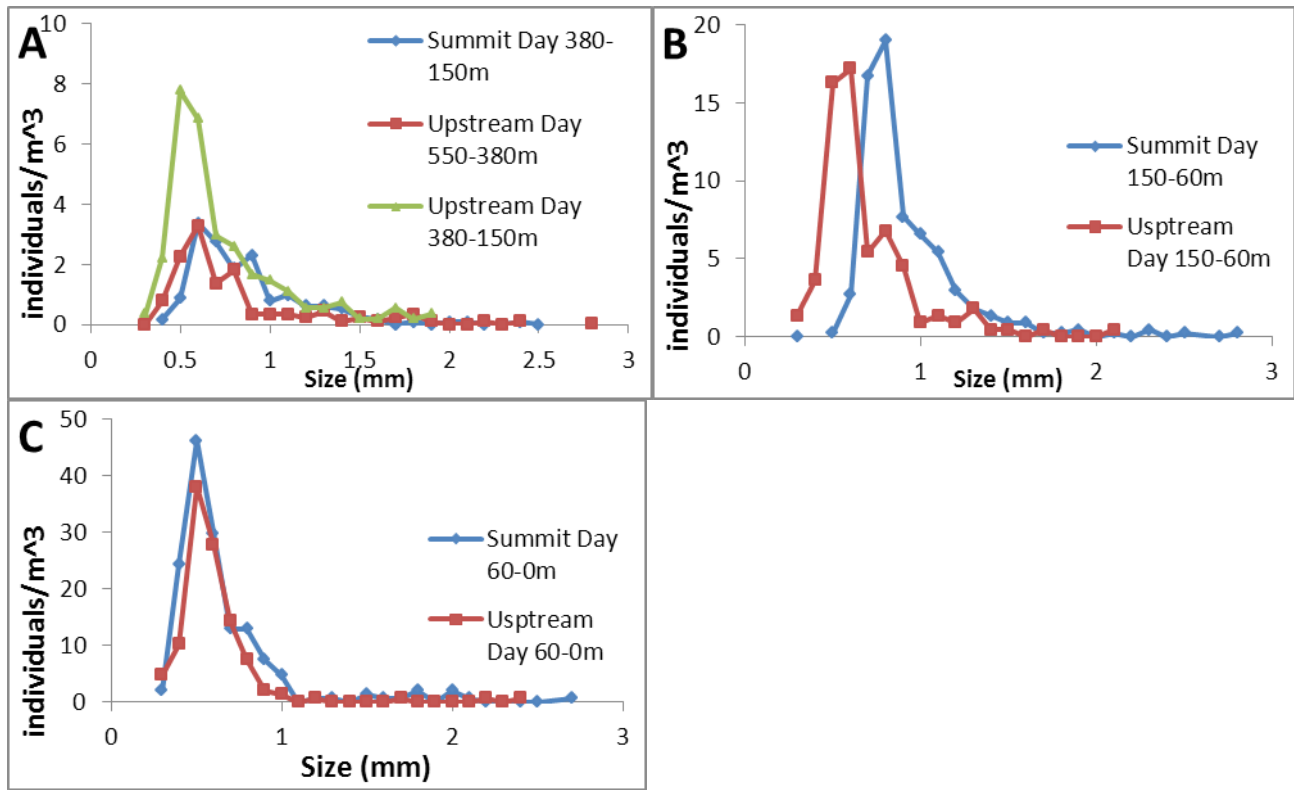


Fig. 3.

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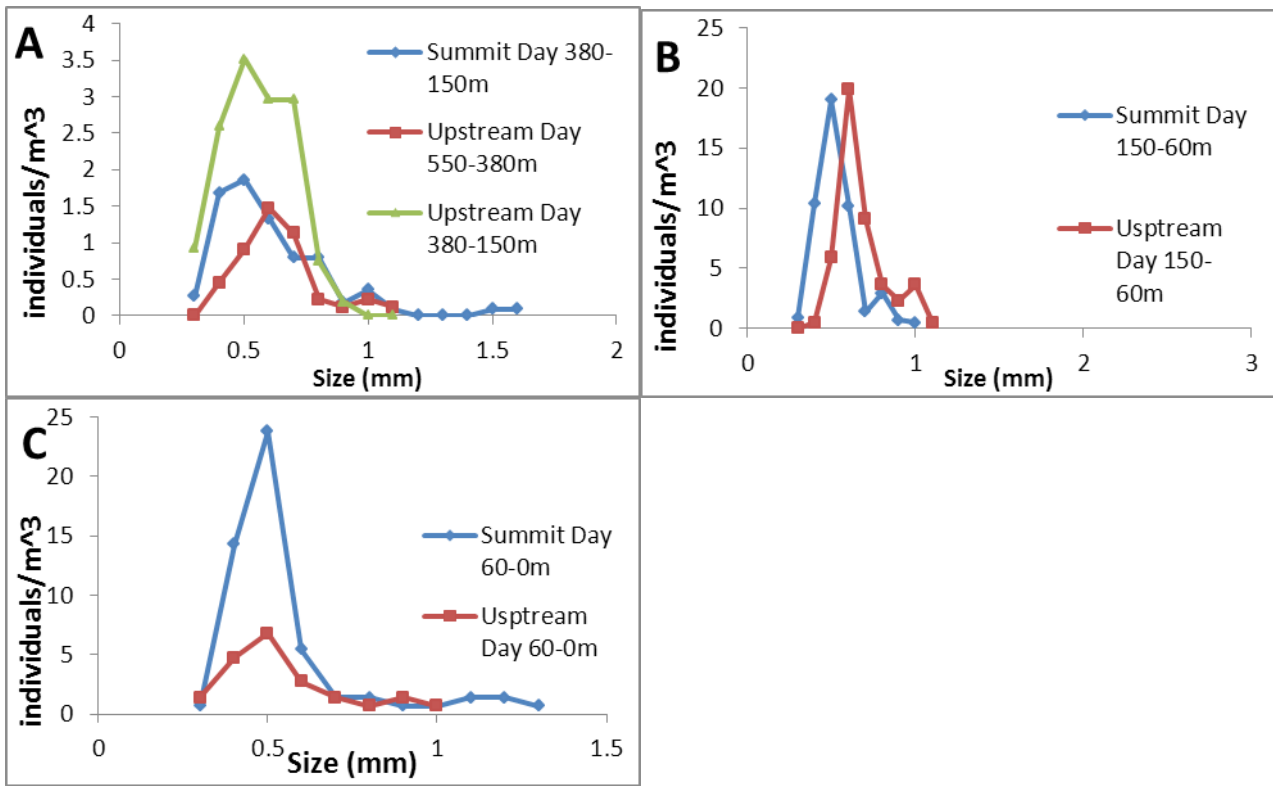


Fig. 4.

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I also feel that I should thank Elvis, but that would be a remarkably silly thing to say, so I will refrain from mentioning Elvis.

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References

- Beckmann, A., and C. Mohn. 2002. The upper ocean circulation at Great Meteor Seamount. *Ocean Dynamics* **52**: 194-204.
- Brinton, E. 1967. Vertical migration and avoidance capability of euphausiids in the California Current. *Limnol. Oceanogr.* **12**: 451-483.
- Christiansen, B, B. Martin, and S. Hirsch. 2009. The benthopelagic fish fauna on the summit of Seine Seamount, NE Atlantic: Composition, population structure and diets. *Deep Sea Res. Part II Top. Stud. Oceanogr.* **56**: 2705-2712, doi:10.1016/j.dsr2.2008.12.032
- De Forest, L, and J. Drazen. 2009. The influence of a Hawaiian seamount on mesopelagic micronekton. *Deep Sea Res. Part I Oceanogr. Res. Pap.* **56**: 232-250, doi:10.1016/j.dsr.2008.09.007
- DeRobertis, A, J. S. Jaffe, and M. D. Ohman. 2000. Size-dependent visual predation risk and the timing of vertical migration in zooplankton. *Limnol. Oceanogr.* **45**: 1838-1844
- Dower, J. F., and D. L. Mackas. 1996. "Seamount effects" in the zooplankton community near Cobb Seamount. *Deep Sea Res. Part I Oceanogr. Res. Pap.* **43**: 837-858.
- Fennel, W. 2009. A nutrient to fish model for the example of the Baltic Sea. *J. Mar. Syst.* **81**: 184-195.
- Genin, A, and G. W. Boehlert. 1985. Dynamics of temperature and chlorophyll structures above a seamount: An oceanic experiment. *J. Mar. Res.* **43**: 907-924.
- Genin, A, L. Haury, and P. Greenblatt. 1988. Interactions of migrating zooplankton with shallow topography: Predation by rockfishes and intensification of patchiness. *Deep Sea Res. Part A Oceanogr. Res. Pap.* **35**: 151-175.
- Gundersen, KR, J. S. Corbin, C. L. Hanson, M. L. Hanson, R. B. Hanson, D. J. Russel, A. Stollar, and O. Yamada. 1976. Structure and biological dynamics of the oligotrophic ocean photic zone off the Hawaiian Islands. *Pac. Sci.* Vol. **30**: 45-68.
- Koslow, J. A. 1997. Seamounts and the ecology of deep-sea fisheries. *Am. Sci.* **85**: 168-176.
- Martin, B, and B. Christiansen. 2009. Distribution of zooplankton biomass at three seamounts in the NE Atlantic. *Deep Sea Res. Part II Top. Stud. Oceanogr.* **56**: 2671-2682, doi:10.1016/j.dsr2.2008.12.026
- Noble, M., and L. S. Mullineaux. 1989. Internal tidal currents over the summit of Cross seamount. *Deep Sea Res.* **36**: 1791-1802.
- Pitcher, T. J., M. R. Clark, T. Morato, and R. Watson. 2010. Seamount Fisheries: Do They Have a Future? *Oceanogr.* **23**: 134-144.
- Rooper, C. N., G. R. Hoff, and A. De Robertis. 2010. Assessing habitat utilization and rockfish (*Sebastes* spp.) on an isolated rocky ridge using acoustics and stereo image analysis. *Can. J.*

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Fish Aquat. Sci. **67**: 1658-1670.

Steinberg, D. K., J. S. Cope, S. E. Wilson, and T. Kobari. 2008. A comparison of mesopelagic mesozooplankton community structure in the subtropical and subarctic North Pacific Ocean. *Deep Sea Res. Part II Top. Stud. Oceanogr.* **55**: 1615-1635, doi:10.1016/j.dsr2.2008.04.025

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Appendix 1. The calculated concentration of zooplankton from the depth zones over the summit during the day.

| | Summit 1 (380-150m) (individuals m ⁻³) | Summit 2 (150-60m) (individuals m ⁻³) | Summit 3 (60-0m) (individuals m ⁻³) |
|------------------------|---|--|--|
| Amphipod | 0.00 | 0.45 | 1.36 |
| Bivalve | 0.09 | 11.77 | 2.72 |
| Calanoid Copepod | 15.77 | 68.59 | 103.22 |
| Chaetognath | 1.68 | 9.05 | 7.47 |
| Cnidarian | 0.00 | 0.00 | 0.68 |
| Copepod Nauplii | 0.18 | 1.36 | 0.68 |
| Crab Larvae | 0.00 | 0.00 | 0.00 |
| Crustacean Larvae | 0.00 | 0.00 | 0.00 |
| Cyclopoid Copepod | 7.53 | 45.95 | 51.61 |
| Echinoderm Larvae | 0.00 | 0.00 | 2.72 |
| Euphausiid | 0.09 | 0.00 | 0.00 |
| Euphausiid (larvae) | 0.00 | 0.00 | 0.68 |
| Foraminifera | 0.09 | 0.91 | 2.04 |
| Gastropod | 0.00 | 0.23 | 2.04 |
| Harpacticoid Copepod | 0.44 | 0.91 | 2.72 |
| Larvacean | 0.35 | 1.13 | 10.19 |
| Oithona copepod | - | - | 46.86 |
| Ostracod | 4.96 | 5.21 | 3.40 |
| Polchaete | 0.00 | 2.26 | 2.72 |
| Pteropod | 0.18 | 2.72 | 1.36 |
| Pteropod (conical) | 0.00 | 0.91 | 0.00 |
| Salp | 0.00 | 0.68 | 1.36 |
| Sapphirina Copepod | 0.00 | 0.45 | 0.68 |
| Shrimp (unbent) | 0.00 | 1.13 | 0.68 |
| Siphonophore | 0.44 | 2.72 | 5.43 |
| Tunicate | 0.00 | 0.23 | 0.68 |
| Total Organisms | 31.80 | 156.64 | 251.93 |

Cross Seamount Zooplankton

Appendix 2. The calculated concentration of zooplankton from the depth zones over the summit during the night.

| Taxa | Summit 4 (380-150m) (individuals m ⁻³) | Summit 5 (150-60m) (individuals m ⁻³) | Summit 6 (60-0m) (individuals m ⁻³) | Summit Night Total (550-0m) (individuals m ⁻³) |
|----------------------|---|--|--|--|
| Amphipod | 0 | 0 | 8.15 | 1.28664 |
| Bivalve | 0.09 | 4.53 | 25.80 | 5.20262 |
| Calanoid Copepod | 10.09 | 94.16 | 80.13 | 41.0629 |
| Chaetognath | 0.65 | 11.77 | 10.86 | 4.89558 |
| Cnidarian | 0 | 0.91 | 0 | 0.21444 |
| Copepod Nauplii | 0.93 | 0.91 | 0 | 0.77491 |
| Crustacean Larvae | 0.19 | 1.81 | 0 | 0.54097 |
| Cyclopoid Copepod | 4.82 | 79.68 | 69.26 | 32.7216 |
| Echinoderm Larvae | 0 | 0 | 2.72 | 0.42888 |
| Euphausiid | 0 | 0 | 2.72 | 0.42888 |
| Euphausiid (larvae) | 0 | 0 | 2.72 | 0.42888 |
| Foraminifera | 2.96 | 0.00 | 5.43 | 2.65126 |
| Gastropod | 0.46 | 1.81 | 25.80 | 4.78348 |
| Harpacticoid Copepod | 0.37 | 0.91 | 1.36 | 0.65307 |
| Larvacean | 0.56 | 8.15 | 2.72 | 2.69513 |
| Oithona Copepod | 7.78 | 55.23 | 35.31 | 23.3643 |
| Ostracod | 2.22 | 13.58 | 13.58 | 6.70613 |
| Polchaete | 0 | 0.91 | 5.43 | 1.0722 |
| Pteropod | 0.09 | 0.91 | 1.36 | 0.48493 |
| Pteropod (conical) | 0 | 0.00 | 1.36 | 0.21444 |
| Salp | 0 | 2.72 | 1.36 | 0.85776 |
| Sapphirina Copepod | 0.09 | 0 | 0 | 0.05605 |
| Shrimp | 0.09 | 0 | 2.72 | 0.48493 |
| Siphonophore | 0.56 | 4.53 | 0 | 1.40848 |
| Tunicate | 0.09 | 0 | 0 | 0.05605 |
| Total Organisms | 32.04 | 282.49 | 298.79 | 133.474 |

Cross Seamount Zooplankton

Appendix 3. The calculated concentration of zooplankton from the reference station and the integrated results from the summit day tows.

| Taxa | Reference (550-0m) (individuals m ⁻³) | Summit Day Total (380-0m) (individuals m ⁻³) | Downstream Day (550-0m) (individuals m ⁻³) | Downstream Night (550-0m) (in- dividuals m ⁻³) | Upstream Day (550-0m) (in- dividuals m ⁻³) |
|--------------------------|--|--|--|---|---|
| Amphipod | 0.22 | 0.32 | 0.15 | 0.33 | 0.07 |
| Bivalve | 0.22 | 3.27 | 0 | 6.98 | 0.89 |
| Calanoid Copepod | 9.33 | 42.08 | 7.11 | 47.82 | 25.70 |
| Cephalopod | 0 | 0 | 0 | 0.15 | 0 |
| Chaetognath | 1.11 | 4.34 | 1.56 | 6.17 | 3.24 |
| Cnidarian | 0 | 0.11 | 0.74 | 0 | 0.15 |
| Copepod Nauplii | 0 | 0.54 | 0 | 1.24 | 1.11 |
| Crab Larvae | 0 | 0 | 0 | 0 | 0.07 |
| Crustacean Larvae | 0 | 0 | 0 | 0.07 | 0.32 |
| Cyclopoid Copepod | 2.67 | 23.59 | 2.52 | 17.15 | 16.88 |
| Echinoderm Larvae | 0 | 0.43 | 0 | 0.59 | 0.15 |
| Euphausiid | 0.07 | 0.05 | 0.07 | 0.44 | 0.00 |
| Euphausiid (larvae) | 0 | 0.11 | 0 | 0.04 | 0.15 |
| Fish Larvae | 0.07 | 0 | 0 | 0 | 0 |
| Foraminifera | 0 | 0.59 | 0 | 0.39 | 22.99 |
| Gastropod | 0 | 0.38 | 0 | 3.22 | 0.67 |
| Harpacticoid Copepod | 0.37 | 0.91 | 0.52 | 1.13 | 1.49 |
| Larvacean | 0.3 | 2.09 | 0.15 | 2.30 | 2.23 |
| Oithona Copepod | - | 7.40 | 1.70 | 10.28 | 12.90 |
| Ostracod | 1.93 | 4.77 | 2.07 | 6.22 | 4.63 |
| Polychaete | 0 | 0.96 | 0.07 | 0.67 | 0.60 |
| Pteropod | 0.37 | 0.96 | 0 | 0.15 | 0 |
| Pteropod Triangles | 0.15 | 0 | 0 | 0 | 0.15 |
| Pteropod (conical) | 0 | 0.21 | 0 | 0.15 | 0 |
| Salp | 0.44 | 0.38 | 0 | 1.33 | 0.08 |
| Sapphirina Copepod | 0 | 0.21 | 0.07 | 0.15 | 0.81 |
| Shrimp | 0.59 | 0.48 | 0.52 | 0.30 | 0.07 |
| Siphonophore | 0.67 | 1.77 | 0.30 | 1.17 | 0.15 |
| Tunicate | 0 | 0.16 | 0 | 0 | 1.41 |
| Unknown Larvae | 0.07 | 0.00 | 0 | 0 | 0.15 |
| Total Individuals | 18.58 | 96.12 | 17.56 | 108.43 | 97.07 |

Cross Seamount Zooplankton

Appendix 4. The calculated concentration of zooplankton from the depth zones from upstream of the seamount during the day.

| Taxa | Upstream 11 (550-380m) (in- dividuals m ⁻³) | Upstream 12 (380-150m) (in- dividuals m ⁻³) | Upstream 13 (150-60m) (indi- viduals m ⁻³) | Upstream 14 (60-0m) (indi- viduals m ⁻³) |
|---------------------------|---|---|--|--|
| Amphipod | 0.00 | 0.00 | 0.45 | 0.00 |
| Bivalve | 0.23 | 0.19 | 4.07 | 0.68 |
| Calanoid Copepod | 9.98 | 21.30 | 42.55 | 61.79 |
| Chaetognath | 0.01 | 2.59 | 5.43 | 11.54 |
| Cnidarian | 0.00 | 0.00 | 0.00 | 1.36 |
| Copepod Nauplii | 0.11 | 2.22 | 0.91 | 0.00 |
| Crab Larvae | 0.00 | 0.00 | 0.45 | 0.00 |
| Crustacean Larvae | 0.57 | 0.00 | 0.00 | 1.36 |
| Cyclopoid Copepod | 4.64 | 14.08 | 45.27 | 19.69 |
| Echinoderm Larvae | 0.00 | 0.00 | 0.00 | 1.36 |
| Euphausiid | 0.01 | 0.00 | 0.00 | 0.00 |
| Euphausiid (larvae) | 0.00 | 0.37 | 0.00 | 0.00 |
| Foraminifera | 70.40 | 2.41 | 0.00 | 2.04 |
| Gastropod | 0.00 | 0.37 | 0.91 | 3.40 |
| Harpacticoid Cope- pod | 1.70 | 0.37 | 1.36 | 5.43 |
| Larvacean | 0.00 | 0.37 | 5.89 | 10.19 |
| Oithona copepod | 2.60 | 9.07 | 19.47 | 46.86 |
| Ostracod | 0.23 | 6.11 | 10.41 | 2.72 |
| Polchaete | 0.00 | 0.56 | 1.36 | 1.36 |
| Pteropod | 0.00 | 0.19 | 0.45 | 0.00 |
| Pteropod (conical) | 0.00 | 0.19 | 0.00 | 0.00 |
| Salp | 0.00 | 0.00 | 4.07 | 1.36 |
| Sapphirina Copepod | 0.00 | 0.00 | 0.45 | 0.00 |
| Shrimp (unbent) | 0.00 | 0.00 | 0.91 | 0.00 |
| Siphonophore | 0.00 | 0.37 | 3.17 | 6.79 |
| Tunicate | 0.00 | 0.00 | 0.00 | 1.36 |
| Total Organisms | 90.47 | 60.75 | 147.58 | 179.27 |

Cross Seamount Zooplankton

Appendix 5. The calculated concentration of zooplankton from the depth zones from downstream of the seamount during the night.

| Taxa | Downstream 10 (550-380m) (in- dividuals m ⁻³) | Downstream 9 (380-150m) (in- dividuals m ⁻³) | Downstream 8 (150-60m) (indi- viduals m ⁻³) | Downstream 7 (60-0m) (indi- viduals m ⁻³) |
|---------------------------|---|--|---|---|
| Amphipod | 0 | 0.09 | 1.81 | 0 |
| Bivalve | 0.06 | 0.74 | 16.30 | 36.67 |
| Calanoid Copepod | 5.55 | 15.00 | 143.96 | 150.75 |
| Cephalopod | 0 | 0 | 0 | 1.36 |
| Chaetognath | 0.06 | 2.04 | 17.20 | 23.09 |
| Copepod Nauplii | 0.28 | 1.02 | 2.72 | 2.72 |
| Crustacean Larvae | 0 | 0.19 | 0 | 0 |
| Cyclopoid Copepod | 0.45 | 6.57 | 54.32 | 50.25 |
| Echinoderm Larvae | 0 | 0 | 0.91 | 4.07 |
| Euphausiid | 0 | 0 | 0.91 | 2.72 |
| Euphausiid (larvae) | 0 | 0.09 | 0 | 0 |
| Foraminifera | 0.06 | 0.19 | 1.81 | 0 |
| Gastropod | 0.11 | 0.56 | 4.53 | 20.37 |
| Harpacticoid Cope- pod | 0.17 | 0.46 | 2.72 | 4.07 |
| Larvacean | 0 | 0.19 | 9.05 | 6.79 |
| Oithona Copepod | 0.40 | 5.37 | 28.07 | 31.24 |
| Ostracod | 0.23 | 4.63 | 15.39 | 16.30 |
| Polchaete | 0 | 0.19 | 1.81 | 2.72 |
| Pteropod | 0 | 0 | 0 | 1.36 |
| Pteropod (conical) | 0 | 0 | 0.91 | 0 |
| Salp | 0 | 0 | 6.34 | 2.72 |
| Sapphirina Cope- pod | 0 | 0 | 0 | 1.36 |
| Shrimp | 0 | 0 | 0 | 2.72 |
| Siphonophore | 0.06 | 0.28 | 3.62 | 4.07 |
| Total Organisms | 7.41 | 37.60 | 312.37 | 365.33 |