Marquesas Islands Mass Effect Study (MIMES):
Correlating Satellite and *In Situ* Oceanographic Measurements with Biological Observations

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Abstract

An episodic Chlorophyll a bloom resulting from the Marquesas Island Mass Effect was observed through *in situ* oceanographic measurement and satellite imagery. Oceanographic data was collected and it supported the theory that blooms are caused by dynamic interaction of currents and topography. Biological samples were also taken to compare the Marquesas Island Mass Effect region to the oligotrophic waters of South Pacific Gyre, and the Marquesas are shown to sustain a higher density of marine organisms.

Introduction

The Island Mass Effect of the Marquesas Islands is the seasonal and episodic occurrence of chlorophyll *a* (Chl-a) blooms in the leeward wake of the island group. The Marquesas are a group of high volcanic islands at 9-11° South latitude and 138-140° West longitude, located in the South Equatorial Current (SEC). *Signorini et al.* (1999) have demonstrated that the turbulent flow and upwelling-inducing eddies caused by the intersection of the islands and the SEC are the driving causes of these blooms. In addition, *Martinez et al.* (2004) created a time series of these blooms from 1997-2001 by using spatially averaged SeaWiFS satellite data. From this time series, we know that the blooms occur seasonally in the austral summer (October-December). However, two of the six bloom events *Martinez et al.* (2004) observed in four years of satellite observations did not occur in the seasonal timeframe. These two episodic blooms occurred during the austral winter (March-May), and include the highest average chlorophyll values of the entire study period. Our cruise track across the Pacific coincided with a potential episodic bloom in May 2009 observed by the Aqua MODIS satellite.

Given the limitations of satellite observation- satellites can only observe the surface layer and their measurement of Chl-a is rarely verified- our study sought to take

in situ measurement of Chl-a to determine whether a bloom is occurring and to examine the oceanographic and biological properties of this potential bloom. In addition, we had the opportunity to compare satellite Chl-a values with the physical measurements we made, using ocean color imagery provided to us by NOAA. There is a scarcity of *in situ* observation of the chlorophyll blooms in this region, so this study aims to create a better oceanographic understanding of what the Marquesas Island Mass Effect is and what its biological effects are.

Our study measured the thermocline, phosphate, Chl-a, and current fields in the water column to the north and south of the island group and to the west of Nuku Hiva, where satellite imagery indicated the most bloom activity. Each of our 12 stations also included a neuston net tow, meter net tow, and bird observations. Based on our background research and understanding of the Island Mass Effect, we anticipated that increased Chl-a, more dynamic currents, higher concentrations of phosphate, and lower SST's, as correlated with satellite Chl-a imagery, would describe the region of the Marquesas Island Mass Effect. We predicted that we would observe overall greater biological productivity in this oceanographically dynamic region relative to the surrounding waters of the South Pacific Gyre.

Methods

We collected data aboard the SSV Robert C. Seamans at stations both inside and outside the lee of the Marquesas Islands. Station locations ranged from approximately 13° South to 1° South in the South Pacific Ocean. The stations in the lee of Nuku Hiva represent the Marquesas Island Mass Effect region and are labeled as stations 020

through 024 (Figure 1). The selection of sampling locations was determined by satellite imagery of the blooms (Figure 2), Acoustic Doppler Current Profiler (ADCP) measurements (Figure 3), and readings from the shipboard flow-through fluorometer. Our use of satellite imagery in particular was novel as we received "one day" images on about a one day delay, allowing us to attempt to intersect different features of the bloom as it rapidly changed. This technique proved to be essential because the bloom was beginning to wane, which in combination with the strong westerly current, meant that we could have missed the bloom entirely.

We measured oceanographic variables including:

- Current magnitude and direction (ADCP; to depth)
- Conductivity-Temperature-Depth (CTD) Profiles (to ~700m)
    - Temperature
    - Salinity
    - Density
- Niskin bottle samples of the water column (to 550m for nutrients; 225m for Chl-a)
    - Phosphate
    - Chlorophyll *a*

In situ oceanographic data was collected at noon and midnight hydrocasts with a CTD profiler and Niskin bottles programmed to collect water at discreet depths. Water samples were tested for chlorophyll, and phosphate concentrations. Chlorophyll *a* was processed by immediate filtration (45 micron filter), acetone absorption, and an approximately 12 hour long freezing period. Samples were further processed by centrifuging and then chlorophyll *a* concentration was taken by a calibrated fluorometer. Measurements were compared to a normalized curve to correct against standards. Phosphate and nitrate concentrations were measured by procedures detailed by Strickland in *A Manual in Seawater Analysis* (1965).

We took biological samples within and without the bloom region. We sampled the surface using a neuston net (335µm) and at depth in the water column with a meter net (335µm). Biovolume measurements were taken by sieving the net contents and determining volume with a graduated cylinder. The biovolumes of zooplankton, jellies, and micronekton from each station were normalized for the length of the tow to provide a biological density value. The 1 meter wide neuston net was towed at a speed of approximately 2 knots for 30 minutes, equating to roughly 1 nautical mile. We also conducted bird observations across the transect, recording abundance and taxonomic group. Observations were conducted during daylight hours with two observers with binoculars on each side of the ship. Observation periods lasted 15 minutes.

Results

The Island Mass Effect of the Marquesas was observed in the oceanographic and biological samples taken on the transect. South of the Marquesas in the SEC at Station 011, Chlorophyll a at the Deep Chlorophyll Maximum (DCM) was relatively low with a value of 0.205 µ/L observed (Figures 6 and 7). SST was high here at 29.2 Celsius (Figures 8 and 9), the current magnitude was low at 77 mm/sec (Figures 10 and 11), and surface phosphate was low as well at 0.298 µ/L (Figures 14 and 15). There was also no east component of the surface currents (Figures 12 and 13). The neuston net collected very low zooplankton densities at 0.0023 mL/m³. There was no meter net deployed at Station 011. 28 birds were observed at this point.

Station 022 located west of the Marquesas showed significantly higher Chlorophyll a both at the surface and at the DCM, with DCM values of 0.490 µ/L

(Figures 6 and 7). The SST was lower than at Station 011 at 28.1 Celsius (Figures 8 and 9), current magnitude was the greatest on the transect at 322 mm/sec (Figures 10 and 11), and surface phosphate was 0.436 µ/L (Figures 15). The east component of the currents was exceptionally weak at -188 mm/sec at the DCM Depth of 50m (Figures 12 and 13). Zooplankton, gelatinous, and micronekton density were all higher in both neuston and meter net samples. Bird observations counted 1 individual.

Station 023 to the east of Station 022 indicated even higher Chlorophyll at the DCM at 0.462 µ/L (Figures 6 and 7). Sea Surface Temperature was relatively low for the transect at 28.7 Celsius (Figures 8 and 9), current magnitude was low at 123 mm/sec (Figures 10 and 11) but with an exceptionally strong east component at 50 mm/sec. (Figures 12 and 13), and surface phosphate was the highest on the transect at 0.580 µ/L (Figures 14 and 15). Zooplankton density was highest on the transect from the neuston at 0.0591 mL/m³ and from the meter net at 0.151 mL/m³. Neuston micronekton density was also highest on the transect at 0.031 mL/m³ as with the meter net at 0.026 mL/m³. Gelatinous density was highest on the transect at 0.045 mL/m³ for the meter net and slightly lower than at Station 022 for the neuston tow. 4 seabirds were counted at the hour nearest to the 023 hydrocast.

Station 029 was located to the north of the Marquesas at about 5 degrees south of the Equator. Chlorophyll a was measured at the DCM to have dropped to 0.262 µ/L (Figures 6 and 7). Sea Surface Temperature dropped very little at this point to 28.6 Celsius (Figures 8 and 9). The current magnitude was 115 mm/sec to the west (Figures 10, 11, 12, and 13), and surface phosphate was relatively high at 0.451 µ/L (Figures 14 and 15). Neuston tows were not conducted at Station 029, but at the nearby and similar

Station 031 the results were no jellies or micronekton and relatively low zooplankton density at 0.007 mL/m³. The was also no meter net at 029, but the 031 meter net took in a fairly low amount of organism with zooplankton density at 0.031 mL/m³. There were 18 seabirds observed here.

Discussion

The data collected along this transect represent a snapshot of the oceanographic and biologic conditions at the time of sampling. At certain stations within the Marquesas, high chlorophyll, lower SST's, higher phosphate, and greater east component of the currents were observed in conjunction with exceptionally high biological densities. This supports the idea that the surface currents moving past the island masses are turbulently mixed, as indicated by the stronger east component opposite the typical SEC flow, and possibly result in vertical mixing of colder, nutrient rich water which stimulates primary production. This increase in primary production likely has a bottom-up effect on the regional ecosystem, functioning as a food source for the organisms which we observed. We observed what *Martinez et al.* described as an episodic bloom event. By comparing the data gathered at certain stations with the satellite Chlorophyll a imagery, we can see that we sampled within a mesoscale eddy which was associated with relatively high biological activity. We observed an overall trend of low biological density in the waters south of the Marquesas in the SEC and north of the Marquesas in sub-equatorial waters with a significantly stronger biological signal in the Marquesas. This fact, in correlation with the *in situ* and satellite oceanographic data, supports our original hypotheses about the Marquesas Island Mass Effect.

However, there is tremendous variability amongst our data set, and though several sample stations support our original hypothesis, several are the exact opposite of what we expected. For example, at station 025 we measured relatively low Chl-a with a relatively fast west current at the depth of the DCM in conjunction with relatively high zooplankton density (Figures 6, 7, 10, 11, 12, 13). We attribute this unexpected result to the tremendous amount of variability within this dynamic current system; high Chlorophyll a does not always align with high biological density, the organisms in question are incapable of swimming against currents and thus become concentrated in certain areas and not in others, and there may be significant lag times between primary and secondary production. In a similar way, the sea bird observations we made did not demonstrate clear trends in regards to this study, but they did provided interesting insights into how higher trophic level species can be dissociated with regions of primary production. This shows that thought the Marquesas may be abundant in zooplankton, this does not translate directly into the presence of higher trophic level organisms like sea birds with complex foraging behaviors. Another factor that may have challenged our study was that the episodic bloom that we observed was not particularly robust in comparison to other events observed in the past. We attribute this bloom relaxation period to a possible weakening of the prevailing South East Trades, and there is a possibility that the inconsistent data we collected resulted from this. We expect that the station by station trends were not as evident because this episodic bloom was relatively small and weak. Also, other parameters we did not measure such as the concentration of iron in the waters could have been significant.

The leeward waters of the Marquesas are shown to standout from both an oceanographic and biological perspective from the ocean surrounding them. We observed that the South Pacific Gyre- as described by the stations to the north and south of the Marquesas- is relatively calm oceanographically. The currents in the vast majority of this ocean were slow and moving in consistent directions, the water was very warm, and phosphate was in limiting concentrations. Biologically, the gyre waters were essentially an ocean desert with low concentrations of chlorophyll a and overall low density of marine organisms. It was not until we neared Marquesas Islands that we began to observe fast moving currents moving in the direction opposite to the South Equatorial Current, lower Sea Surface Temperatures, and also high concentrations of phosphate in the surface waters. At the same time our neuston and meter nets began to fill up with significant quantities of zooplankton, jellies, and micronekton. The down current waters of the Marquesas were a biological oasis relative to the oligotrophic gyre in which they stand.

Conclusion

The dynamic nature of the Marquesas Island Mass Effect has become evident to us through our examination of this region. It not possible to say that the Marquesan waters are entirely more productive than SEC or Equatorial waters; at certain stations we found the opposite to be true. However, the Marquesas stand out as an oceanographically complex region with overall higher biological activity. We are unable to point to any one physical variable to describe how the Marquesas Island Mass Effect functions. Rather, we

have come to understand that several oceanographic variables control the biology of the Marquesan waters.

This study is significant because it elucidates the process which possibly contributes most to the Marquesas Island Mass Effect- the dynamic interaction between surface currents and topography. The improved understanding of the oceanographic features of the region, which are shown to result from surface currents interacting with topography, shows us how what would otherwise be an oligotrophic ocean desert can become a thriving marine oasis. This study attempts to quantify the enhanced biological activity associated with the Marquesas Islands, demonstrating how these waters support a rich, complex ecosystem. These waters are used commercially by longline fishermen, and there is large bycatch of untargeted species associated with this activity. It is therefore imperative that the unique and potentially fragile nature of this oceanic oasis be taken into account in future regulatory decisions.

References

Martinez , Elodie and Maamaatuaiahutapu, Keitapu. *Island mass effect in the Marquesas Islands: Time variation* Geodetic Observatory of Tahiti/Terre-Ocean/Universite de la Polynesie Francaise, Faaa, French Polynesia 2004

Signorini, S. R., C. R. McClain, and Y. Dandonneau (1999*), Mixing and phytoplankton bloom in the wake of the Marquesas Islands*, Geophys. Res. Lett., 26(20), 3121– 3124.

Strickland, J.D.H. and T.R. Parsons, 1965. A Manual of Sea Water Analysis. Queen's Printer: Ottowa.

Figures and Tables

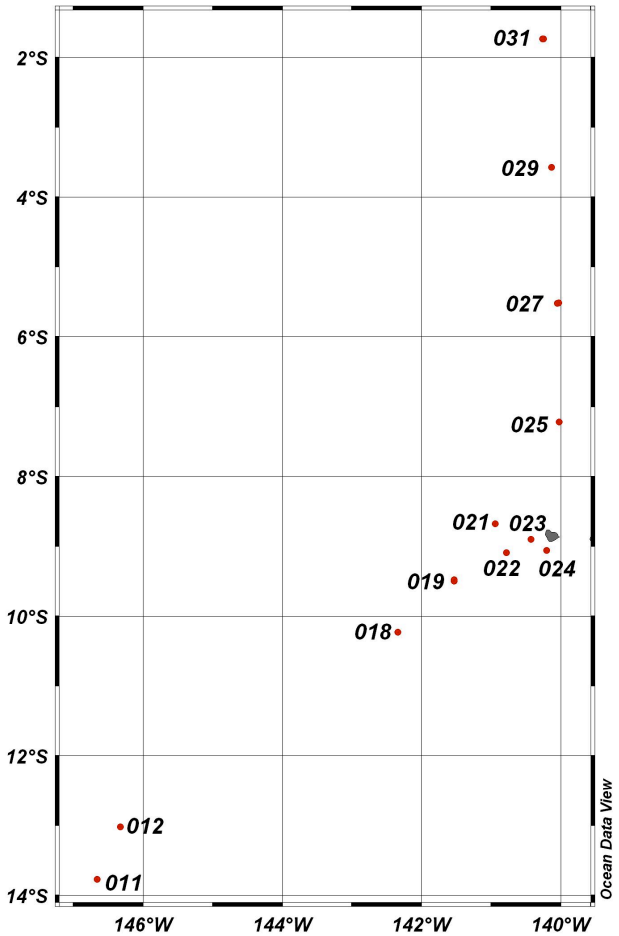

Figure 1: Locations of sample stations along the MIMES transect

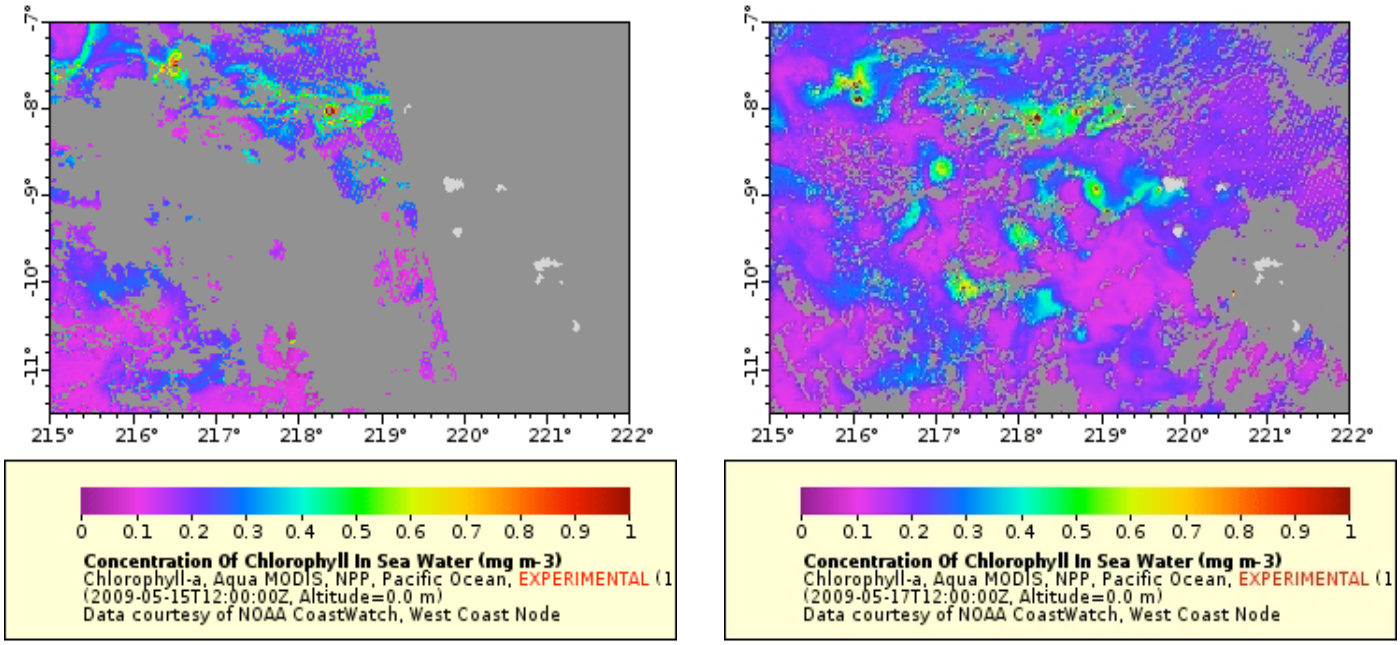

Figure 2: Aqua MODIS satellite 1 day images of Chlorophyll a from 15-May-2009 (left) and 17-May-2009 (right)

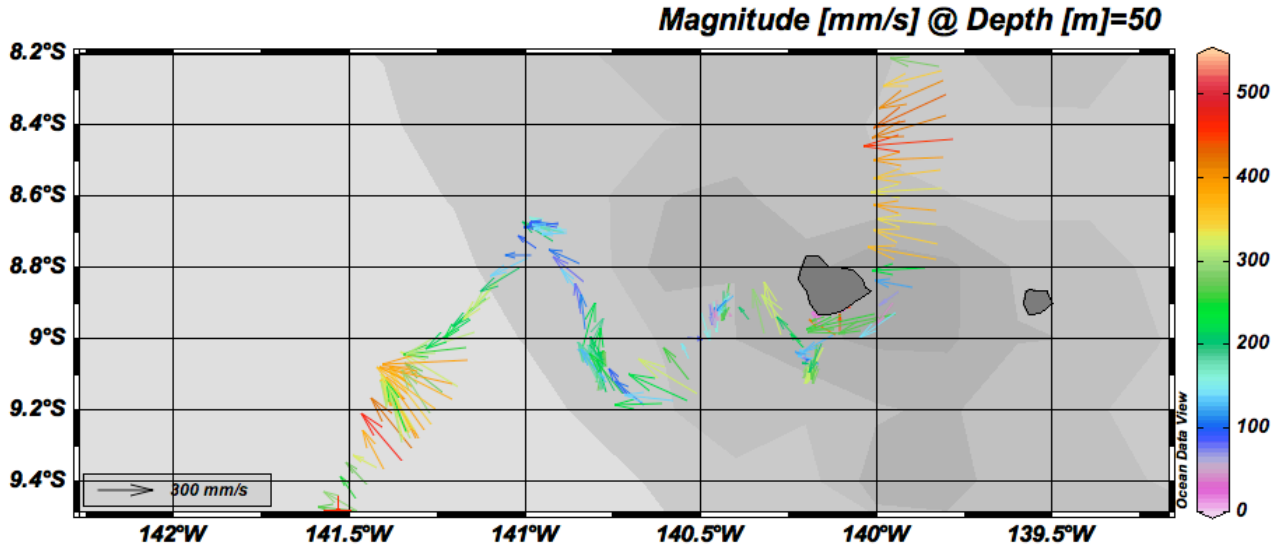

Figure 3: Current magnitude (mm/s) and direction near the Marquesas

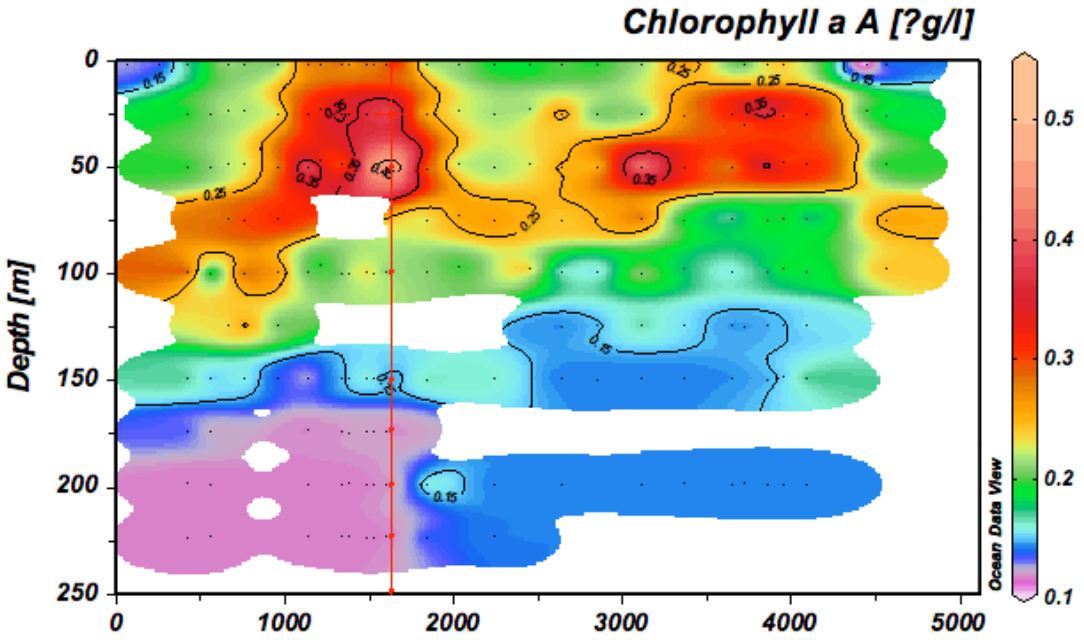

Figure 4: Chlorophyll a (g/l) with Depth (m) along the transect (km)

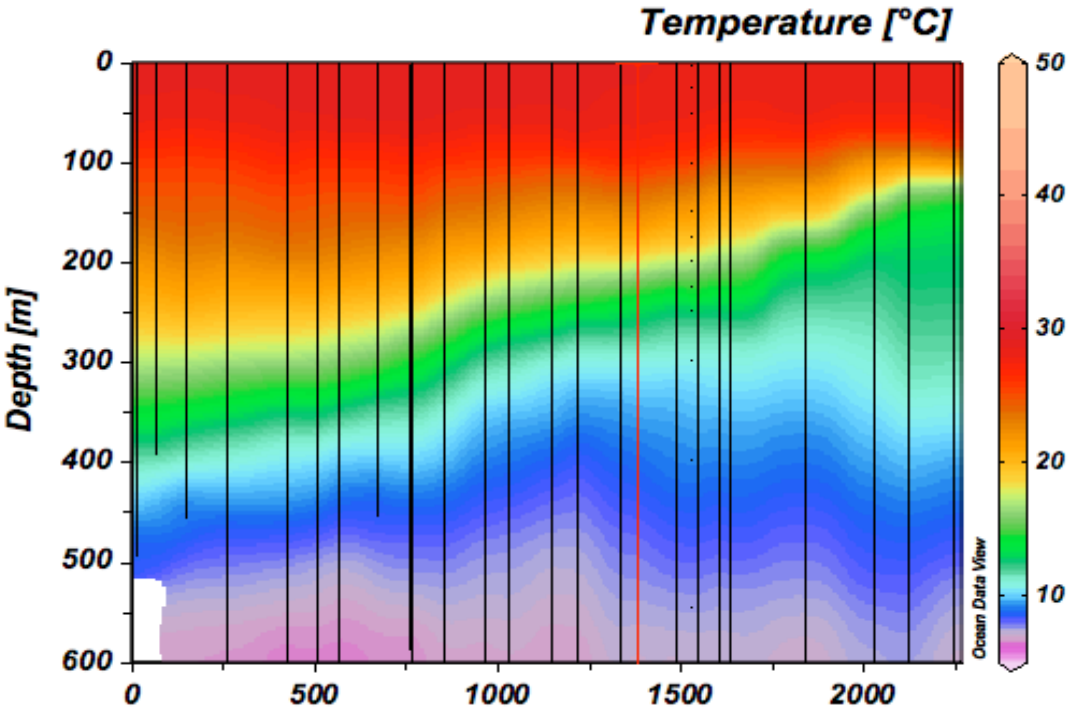

Figure 5: Temperature (Celsius) with Depth (m) along the transect (km)

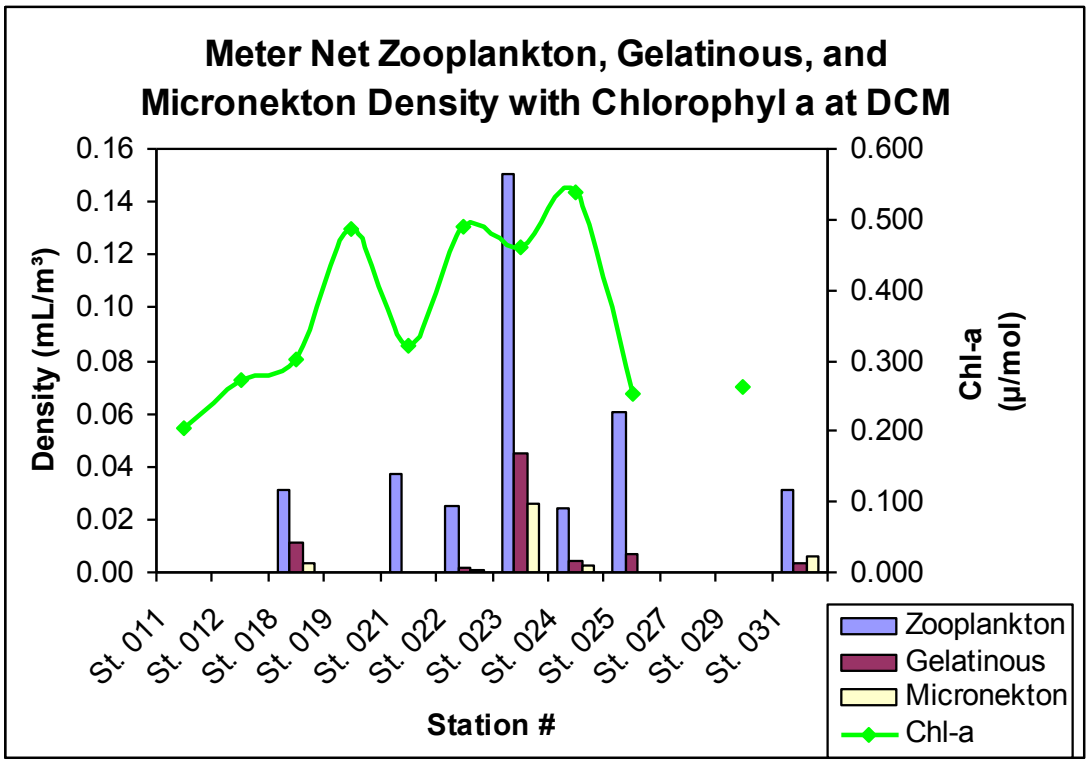

Figure 6: Densities of zooplankton, jellies, and micronekton in mL/m³ taken in the meter net compared with the extracted Chlorophyll a from the DCM

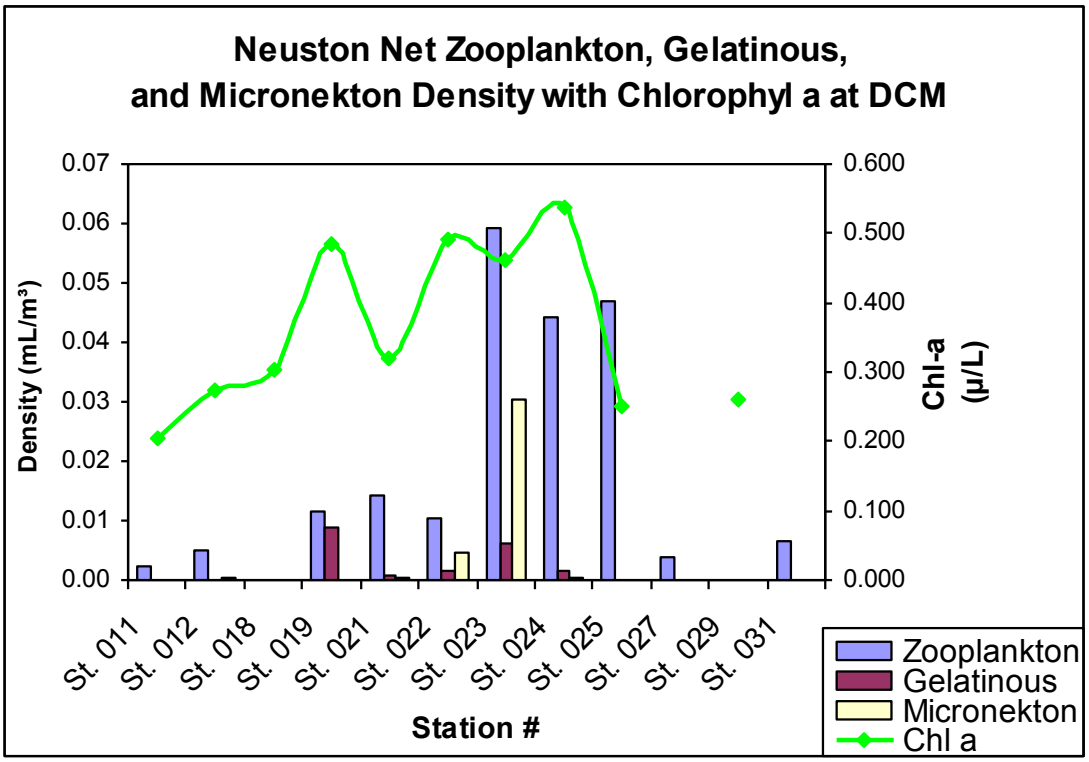

Figure 7: Densities of zooplankton, jellies, and micronekton in mL/m³ taken in the meter net compared with the extracted Chlorophyll a from the DCM

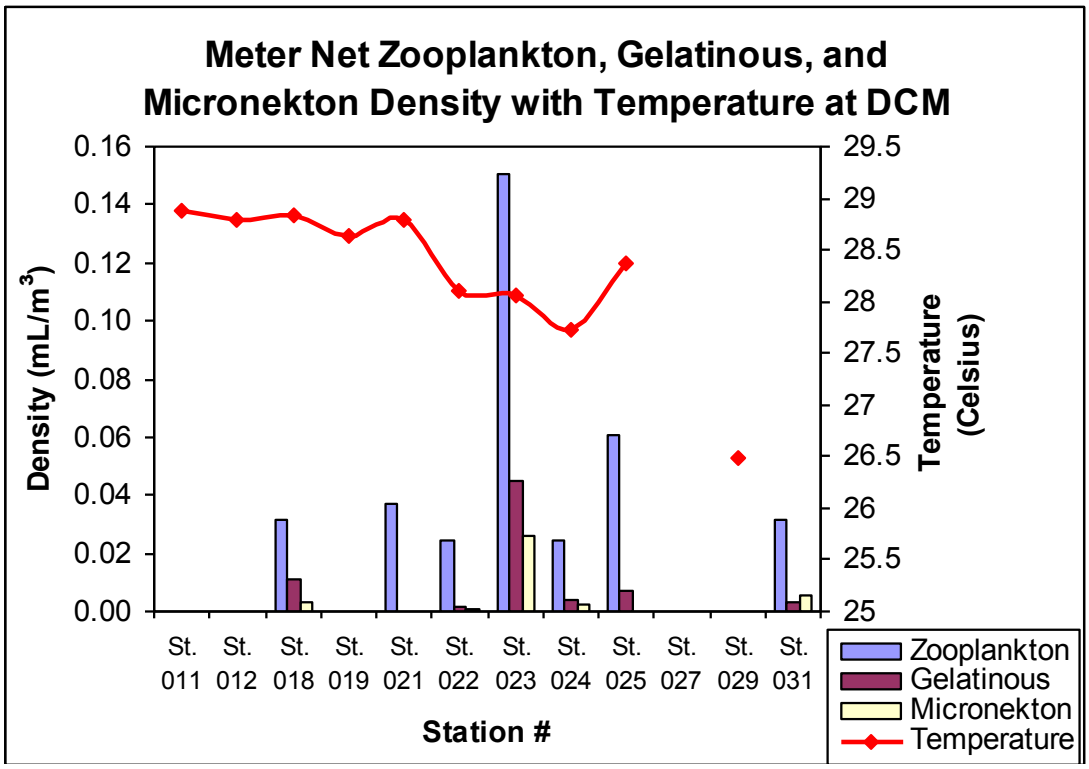

Figure 8: Densities of zooplankton, jellies, and micronekton in mL/m³ taken in the meter net compared with water Temperature (°C) at the DCM depth

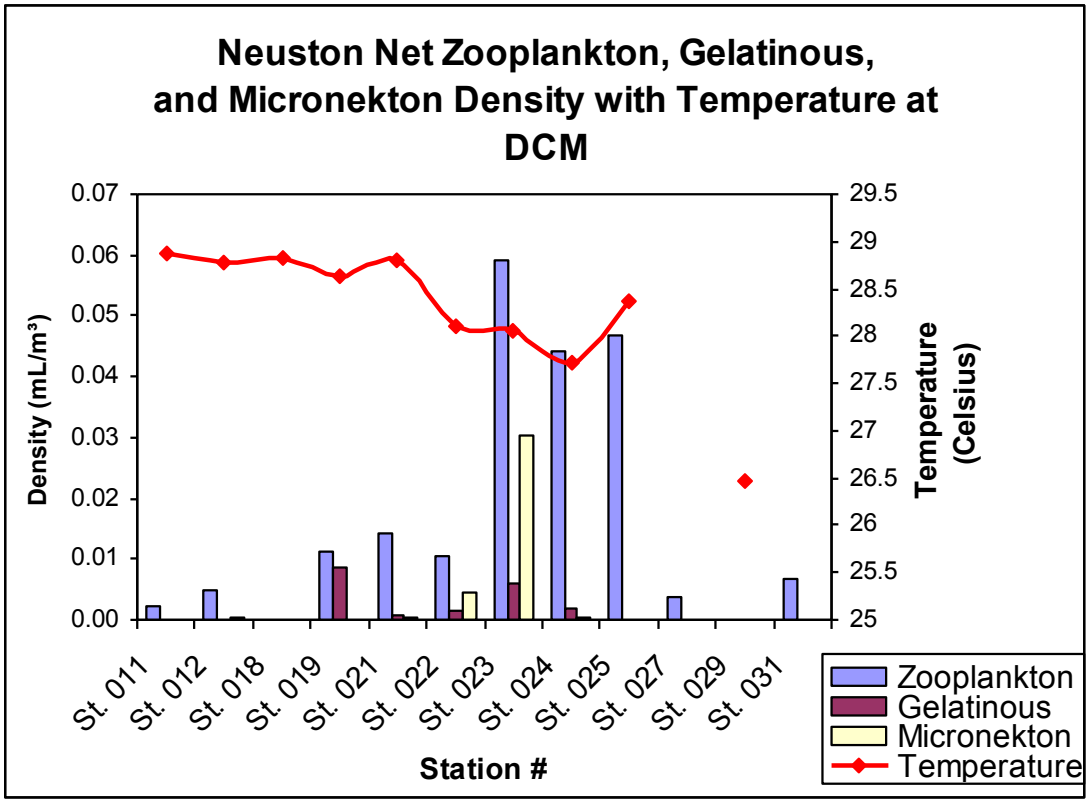

Figure 9: Densities of zooplankton, jellies, and micronekton in mL/m³ taken in the neuston net compared with water Temperature (°C) at the DCM depth

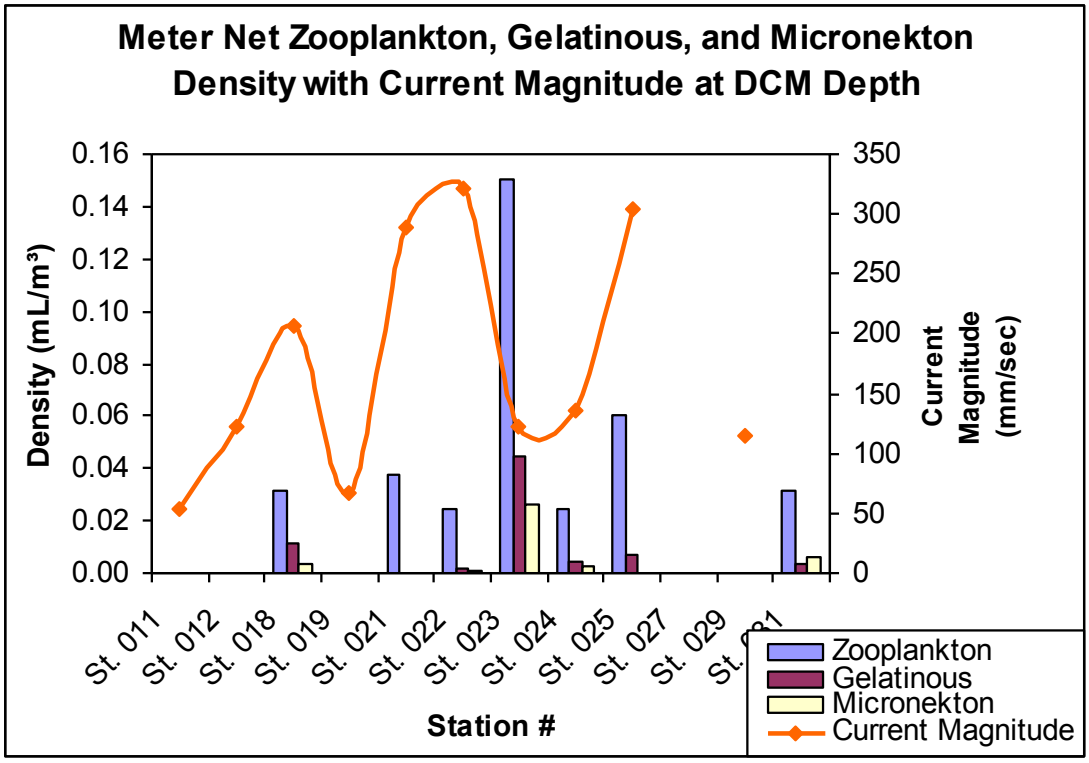

Figure 10: Densities of zooplankton, jellies, and micronekton in mL/m³ taken in the meter net compared to current magnitude at the depth of the DCM

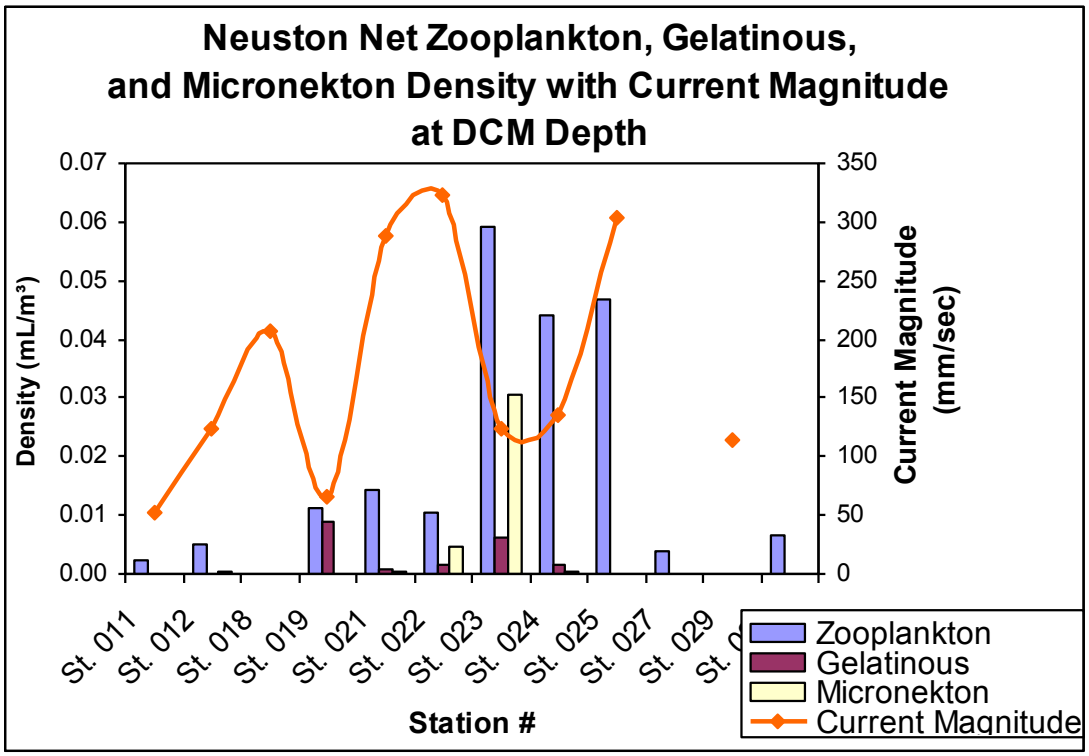

Figure 11: Densities of zooplankton, jellies, and micronekton in mL/m³ taken in the neuston net compared to current magnitude at the depth of the DCM

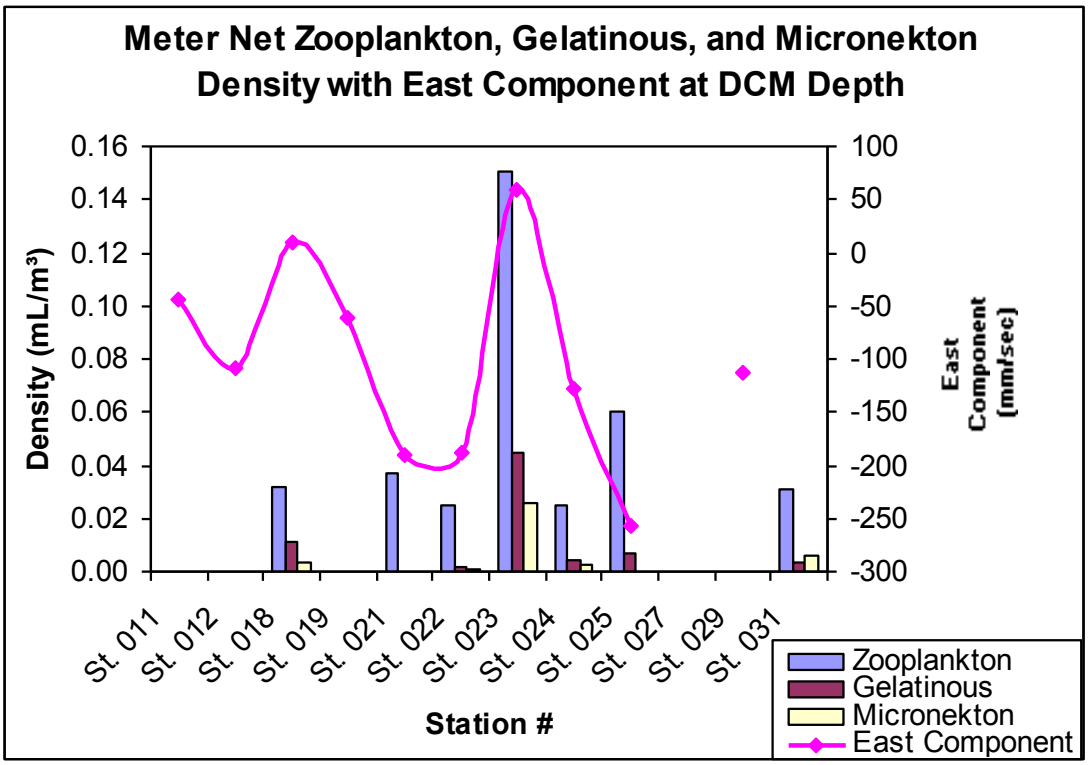

Figure 12: Densities of zooplankton, jellies, and micronekton in mL/m³ taken in the meter net compared with the east component of the current at the depth of the DCM

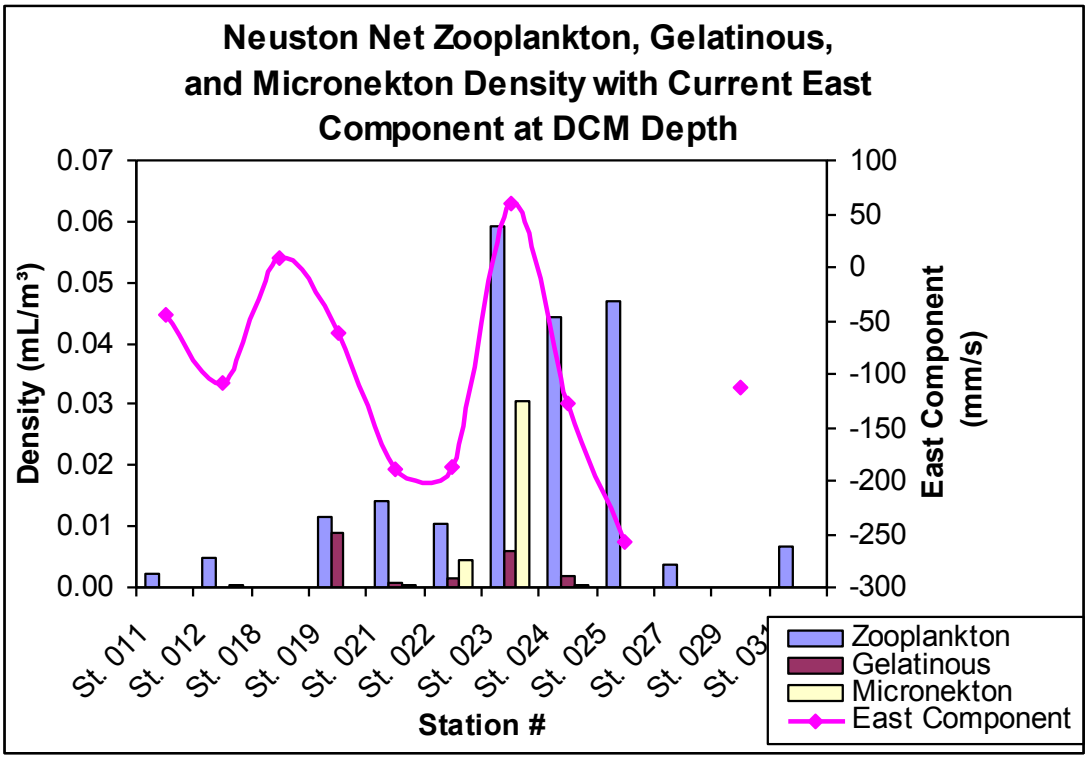

Figure 13: Densities of zooplankton, jellies, and micronekton in mL/m³ taken in the neuston net compared with the east component of the current at the depth of the DCM

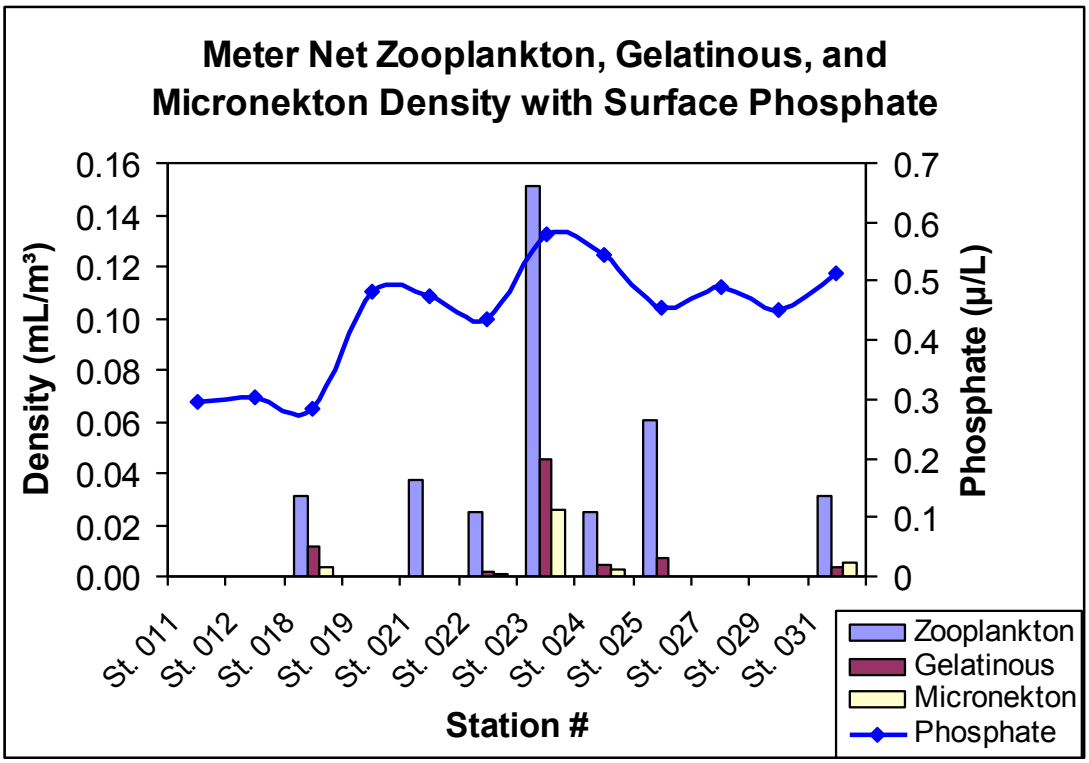

Figure 14: Densities of zooplankton, jellies, and micronekton in mL/m³ taken in the meter net compared to surface phosphate concentrations

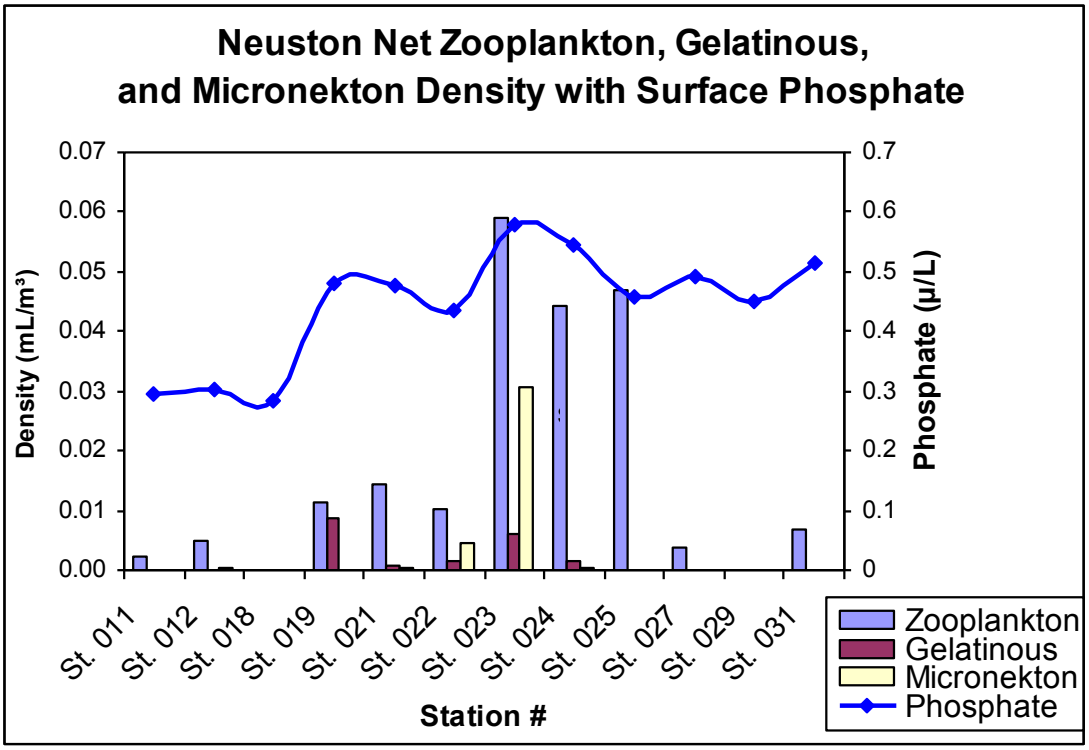

Figure 15: Densities of zooplankton, jellies, and micronekton in mL/m³ taken in the meter net compared to surface phosphate concentrations