A comparison of zooplankton assemblages in a coastal upwelling and offshore station in East Sulu Sea

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ABSTRACT

Partially enclosed marine basins often display characteristic pelagic faunal compositions reflecting their distinctive hydrographic conditions. Seasonal upwelling along the northern coast of the Zamboanga Peninsula in East Sulu Sea results to the high fisheries production in the area likely by enhancing local plankton abundance. Zooplankton in this area were investigated during the Joint PhilEx oceanographic cruise on board the R/V *Melville* in December 2007. Data on the abundance and vertical distribution of major groups of zooplankton were analyzed and compared between two sets of MOCNESS samples collected from a coastal upwelling station and the other from an offshore station. Eighty four (84) zooplankton taxa belonging to 20 major groups were identified in the coastal station, while ninety five (95) taxa under 28 major groups were found in the offshore station. The total zooplankton density was much higher in the coastal station (98.9 ind./m^3) than in the offshore station (47.5 ind./m^3). Copepods dominated in both stations, comprising up to 70% of the total zooplankton. No distinct variation in the abundance, composition and distribution of zooplankton with depth was observed except in 150 – 200 m depth stratum in the coastal station wherein a dramatic increase in the abundance of copepods, ostracods and chaetognaths was noted. In the offshore station, the crustaceans also showed a drastic increase in abundance in the 50 – 100 m depths. These appear to be related to the thermocline in both stations, where typically higher upper layer primary productivity can support dense communities of zooplankton.

Keywords: upwelling, thermocline, zooplankton, Sulu Sea

INTRODUCTION

The Sulu Sea is one of the major regions that contribute to high fisheries production in the Philippines. It is a deep marine basin with sills shallower than 200 m, restricting deep water circulation that may lead to anoxic conditions (Linsley et al., 1985). The water is fresher and more oxygenated in the northern part of the Sulu Sea because deep waters are replenished only through Mindoro Strait, where a deep (420m) channel connects the Sulu Sea to the South China Sea (Linsley et al., 1985; Quadfasel et al., 1990; Jones, 2002). This type of marine habitat exhibits a characteristic faunal composition reflecting its distinctive warm waters in the mesopelagic and deeper layers. The extent of decrease of zooplankton with depth in this semi-enclosed basin is greater than in the open oceans. This observation suggests that the vertical distribution of zooplankton could be set by the local and unique processes that differ from those in typical open oceans (Nishikawa et al., 2007).

The environment of the Sulu Sea is strongly influenced by the monsoons (Beaufort et al., 2003). Upwelling develops in the leeward side of major islands (Mindoro, Panay, Negros and Zamboanga Peninsula) along the eastern border of the Sulu Sea during the Northeast Monsoon (Miki et al., 2008). Such processes provide an opportunity to examine the response of zooplankton to increased primary productivity.

The information on the pelagic fauna in the Sulu Sea is limited to primary production and chlorophyll distribution (San Diego-McGlone et al., 1999; Jones, 2002; Gomez et al., 2005; Miki et al., 2008). The few studies on zooplankton focused on fish larvae (Campos and Estremadura, 2003), chaetognaths (Johnson et al., 2006) and mesozooplankton (Nishikawa et al., 2007), but were based on samples collected in oceanic areas of the Sulu Sea.

This study compares vertical patterns in the abundance and distribution of zooplankton in a coastal upwelling and offshore station in Eastern Sulu Sea off the coast of the Zamboanga Peninsula.

MATERIALS AND METHODS

Plankton were collected in the Sulu Sea during the Philippine Strait Dynamics Experiment (PhilEx) cruise on board the R/V *Melville* from 20 November to 17 December 2007. A total of ten (10) stations along a transect extending from the coast of Zamboanga Peninsula (N8°11.47’, E122°38.16’) to about 206 km offshore were surveyed. A 10-net MOCNESS (Multiple Opening-Closing Net and Environmental Sensing System), with net dimensions of 1m x 1.25m and bags with 335 μm mesh size (Wiebe et al., 1976), was deployed in two of the stations, namely station 37 along

Table 1. Depth layers where zooplankton were sampled in the Sulu Sea.

Net no.	Depth strata	Net no.	Depth strata
1	0 – 400m	**6**	200 – 150m
2	400 – 350m	**7**	150 – 100m
3	350 – 300m	**8**	100 – 50m
4	300 - 250m	**9**	50 - 0m
5	250 - 200m	**10**	0m

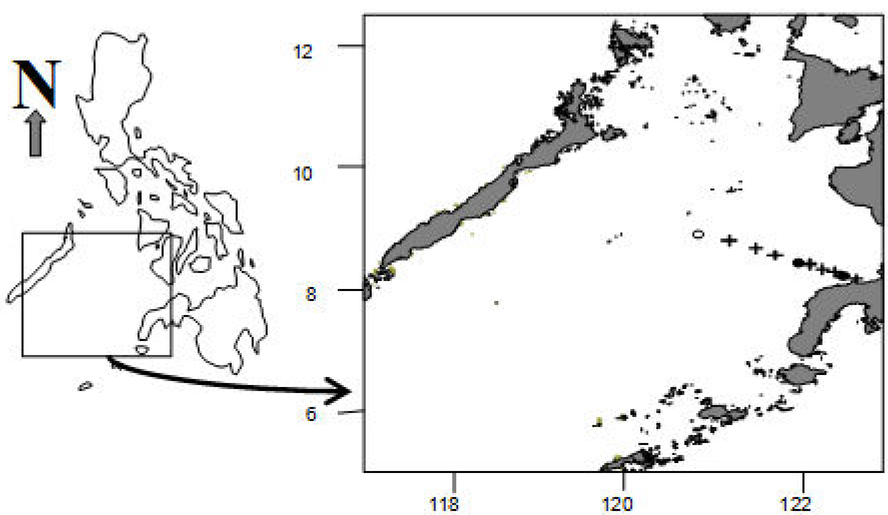


Figure 1. Location of stations along the Zamboanga peninsula transect. Legend: ● – MOCNESS stations compared in this study; o – MOCNESS excluded in this study; + - other stations where nutrient and chlorophyll data presented in this study were collected.

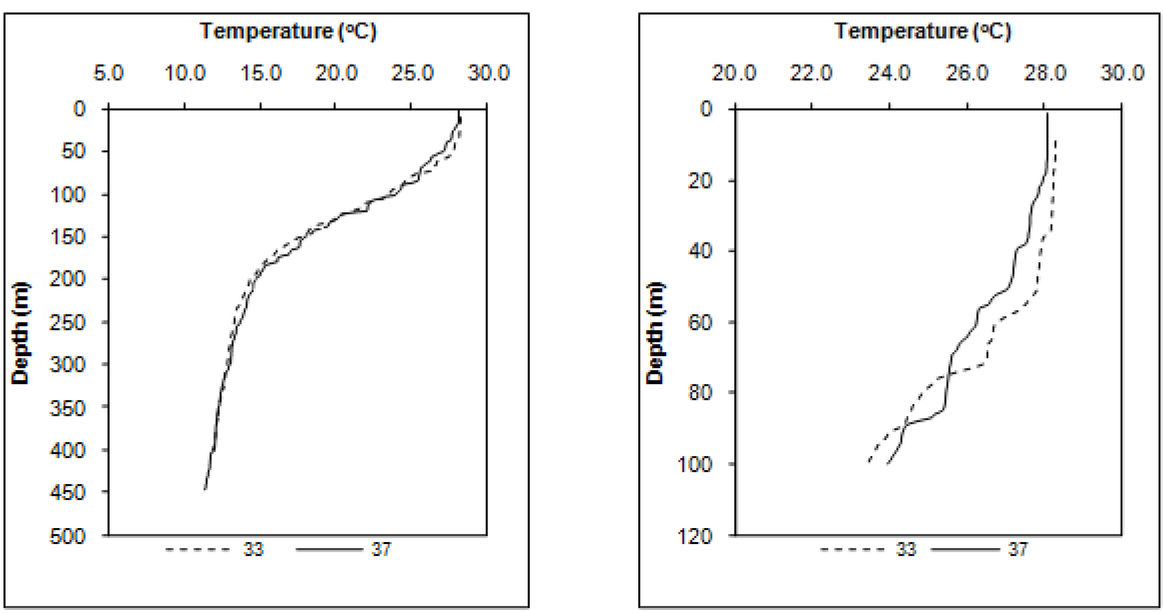
the coast (11.5 km out) and station 33 about 72 km from the coast. Samples were collected from ten (10) different depth strata at 50m depth intervals from the surface down to a maximum depth of 400 m (Table 1). Aside from the first net, which was open from the surface to the deepest (400 m) point sampled, all other nets were fished for approximately 15 minutes at their designated strata. At each station, temperature and salinity were measured with a CTD profiler attached to the MOCNESS.

Station 37 is a potential upwelling area located along the coast of Zamboanga Peninsula and station 33 is an oligotrophic area located about 72 km from the coast (Figure 1). Unfortunately, nets 7 to 10 assigned to the depth strata from 150 m to 0m in the coastal station (37) malfunctioned. Upon retrieval of the MOCNESS, a double oblique tow (DOT) was done using a 60 cm diameter ringnet fitted with a 335 um mesh net to cover the layer from 100 m to the surface. This DOT sample was used in place of the missed MOCNESS samples.

All samples were fixed in 10% seawater-formalin solution and taken back to the lab for processing, sorting and identification. Subsampling was done using a plankton splitter. Aliquots ranged from 1/32 to ¼ of the original sample. Zooplankton were first identified into major taxonomic groups; then calanoid copepods, the most abundant group, were further identified to family level, to allow a more detailed examination of their vertical distribution. Densities were computed as number of individuals per m^3.

To examine the decrease in abundance with depth, linear regression analysis was done to the $\log_{10}$-transformed abundance data. Cluster analysis was done on relative abundance (%) data using the Bray-Curtis Index of dissimilarity and flexible (ß = -0.25) sorting strategy to group species and stations. The COMM program was used to do the cluster analysis (Piepenburg and Piatkowski, 1992).

Data for chlorophyll *a* and nutrients were provided by the chemical oceanography component of the cruise, which analyzed samples collected along most of the stations along the transect shown earlier, aside from 2 – 3 stations wherein the CTD Rosette water sampler malfunctioned.



a b

Figure 2. Vertical profile of temperature in stations 33 and 37. a) 0 – 400m, and b) 0 – 100m.

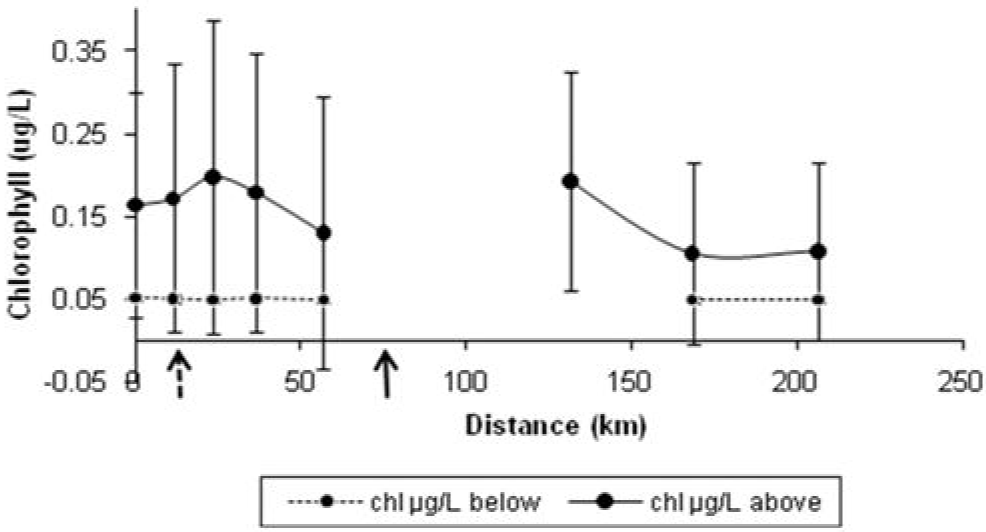


Figure 3. Spatial distribution of chlorophyll *a* above and below the thermocline (200m) in stations along the Sulu Sea transect. Arrows indicate location of stations 37 (11.5 km) and 33 (72 km) from the coast.

RESULTS AND DISCUSSION

Hydrography

The depth and shape of the thermocline is similar in the two stations, where temperature decreased rapidly from 50 – 200 m (Figure 2a). Temperature decreased more gradually below 200 m and seemed to be nearly constant at 10 ^{o}C in deeper layers. This agrees with the vertical profiles reported by Quadfasel et al. (1990) and Jones (2002) for the Sulu Sea. Figure 2b shows that for the same depth, water in station 37 is slightly cooler down to 75 m (25.5 – 28.0 ^{o}C) than water in the same layer in the offshore station (26.5 – 28.3 ^{o}C). This is an indication of a weak upwelling near the coast, where vertical mixing results to a decrease in surface temperature by entraining cold water from deeper layers (Wang et al., 2006; Miki et al., 2008). This pattern changed at depths below 75 m where the deeper water was slightly warmer closer to the coast.

Overall, the concentration of chlorophyll *a* was lower in the 200 – 400 m depth layer compared to the layer above it (Figure 3). The spatial variation in chlorophyll *a* detected in the 0 – 200 m layer showed a gradual decrease in concentration from the coast toward the central part of the basin. Below 200 m, the concentration of chlorophyll remained the same throughout the transect and was lower than concentrations nearer the surface. The difference in chlorophyll concentrations between surface water and the layer below the thermocline showed a parallel trend across the whole transect, except for the slight decline before the offshore end of the transect. The relatively higher concentration of chlorophyll *a* near the coast is also indicative of a potential upwelling. Nitrate-nitrite concentrations at given depths also showed higher values closer to the coast (Jacinto, *pers comm.)*. This is also consistent with the upwelling area near the coast, although not indicative of a strong upwelling.

Zooplankton Abundance

The combination of environmental conditions and phytoplankton concentration are some of the main factors controlling the spatial and vertical distribution of the pelagic fauna in the Sulu Sea. Zooplankton concentrations over the water column from 0 – 400 m in station 37 ranged from 15.7 – 373.7 ind./m^3, and showed high values up to 200 m (average = 254.3 ind./m^3), before dropping to an average of 21.3 ind./m^3 in deeper water. This planktocline corresponds closely to the highly stratified water column. Linear regression did not show a significant decrease in zooplankton abundance with increasing depth in the coastal station

Table 2. Total abundance of zooplankton for every depth layer sampled from 0 – 400 m. Highest densities for each station are highlighted.

	Stn 33(off)		Stn 37(coast)	
Depth (m)	Density (ind/m^3)	% total	Density (ind/m^3)	% total
0-50	**147.7**	**38.9**	134.9	22.7
50-100	130.9	34.5		
100-150	27.5	7.2		
150-200	16.1	4.3	**373.7**	**62.9**
200-250	8.2	2.2	15.7	2.6
250-300	24.1	6.3	25	4.2
300-350	13.8	3.6	25.2	4.2
350-400	11.2	2.9	19.3	3.2
Total (0 - 400m)	*379.5*	*100*	*593.7*	*100*

*% refers to the entire water column sampled

($p > 0.05$; $r^2 = 0.50$). This is due more to the lack of data points for depths above the thermocline (Fig. 4), resulting from the malfunctioning of the MOCNESS, rather than the absence of a trend. The latter of course is reflected by high abundances in near-surface waters and low abundances beneath the thermocline. In both coastal and offshore stations, densities (mean values = 21.3 and 14.3 ind./m^3, respectively) in layers below the thermocline (200 – 400 m) were from 6 – 12 times less than those at the surface (254.3 and 80.6 ind./m^3, respectively; 0 – 200 m). This is typical of most waters since primary productivity and the resulting food availability is higher in the photic zone. It is only in the offshore station (33) that the decrease is significant ($p < 0.05$, $r^2 = 0.70$). Hence, even with ill-fitting regressions, the decrease in abundance from upper to deeper layers is clear in both stations. Furthermore, the change in the coastal station is somewhat steeper as shown by the fitted lines. Zooplankton abundance in station 33 ranged from 8.2 – 147.7 ind./m^3, with highest values in the 0 – 100 m depth layer. The average density for the upper layer in this station (80.6 ind./m^3) is only about 1/3 the average density in the upper layer in the coastal station (Table 2). Higher average above-thermocline zooplankton density along the coast, as well as deeper occurrences of higher densities (offshore: 0 – 100 m; coast: 0 – 200 m; Table 2) and larger vertical density differences in the coastal station are not inconsistent with upwelling conditions in this area.

Taxonomic Composition and Vertical Distribution

There were no differences in the ratio of holoplankton and meroplankton although there were generally more organisms recorded in the coastal station (Table 3). Since local production of meroplankton by benthic adults is generally higher along the coast (Archambault et al., 1998), the lack of a difference in holoplankton – meroplankton ratio might suggest that horizontal mixing extends from the coast to the offshore station. However, there are substantial differences in the composition of the meroplankton between the 2 stations. Meroplankton in station 33 were more diverse and included different kinds of worms like Platyhelminthes, Annelids and Sipunculids (Table 3). Because of the depth in the offshore station, it is possible that the diverse assemblage of meroplankton in this station is the result of mixing with waters other than from the Zamboanga Coast. It therefore seems that there is little horizontal mixing between coastal waters and those 70 km offshore. This is consistent with the slight differences in chlorophyll *a* concentrations (Figure 3) mentioned above and the differences in the vertical distribution of zooplankton abundance (Table 2).

Among the major groups of zooplankton, copepods were the most abundant, contributing 69.9% on average (69.3 – 70.6%) to the total zooplankton abundance (Table 3) with little difference between the two stations.

Other zooplankton taxa contributed less than 9% to the overall zooplankton. Ostracods ranked second to copepods in the offshore and coastal stations, contributing 5.7% and 8.7%, respectively. Other crustaceans were of minor importance and the remaining taxa had relative abundances of < 5%. This result where Copepoda is the dominant taxa is similar to those reported for other marginal tropical seas and coastal areas (Vinogradov, 1970).

Table 3. Total abundance (0 – 400 m) of major groups of zooplankton and their relative compositions to the total abundance in the 2 stations in the Sulu Sea.

	Stn 33		Stn37	
Major Groups	Density (ind./m^3)	%	Density (ind./m^3)	%
Holoplankton	*42.9*	*92.4*	*90.5*	*91.5*
Copepoda	32.45	70.00	68.52	69.25
Ostracoda	2.62	5.66	8.65	8.74
Protozoa	2.24	4.83	4.43	4.48
Chaetognath	2.05	4.43	4.25	4.30
Mysidacea	1.19	2.56	1.35	1.37
Urochordata	0.94	2.02	0.22	0.22
Euphausiacea	0.69	1.50	2.93	2.96
Cnidaria	0.65	1.40	0.18	0.18
Hydroida	0.02	0.04	-	-
Meroplankton	*3.5*	*7.6*	*8.4*	*8.5*
Mollusca	1.17	2.53	4.90	4.95
Amphipoda	0.69	1.49	0.69	0.70
Decapoda	0.39	0.85	1.56	1.58
Fish	0.35	0.75	0.61	0.62
Cladocera	0.23	0.50	0.13	0.13
Polychaete	0.21	0.46	0.39	0.40
Echinodermata	0.13	0.28	0.05	0.05
Cirripedia	0.06	0.12	0.01	0.01
Isopoda	0.01	0.02	0.02	0.02
Tanaidacea	0.001	0.00	0.04	0.04
Bryozoa	0.25	0.54	-	-
Sipunculida	0.001	0.01	-	-
Platyhelminthes	0.001	0.01	-	-
Brachiopoda	0.001	0.01	-	-
Nematoda	-	-	0.001	0.001
	46.4	***100***	***98.9***	***100***

The variability in the vertical distribution of numbers of copepods is subject to almost the same factors as those affecting the changes in the total amount of zooplankton since they make up the majority of the plankton at all depths. Copepods were observed to have higher densities in the upper 200 m where other biological factors, such as light intensity and food availability, are most favorable (Figure 5). Protozoans, chaetognaths, ostracods and mollusks were also recorded mainly in the upper 200 m in both stations, especially in the 150 – 200 m layer near the coast. The vertical pattern of distribution of chaetognaths was similar to the profile reported by Johnson et al. (2006), where they are concentrated only in the upper 200 m. Mollusks, with the high contribution of gastropods, were also distributed within the thermocline, but with considerable abundance that extends to deeper layers in the coast (Figure 5). This may be due to the local reproduction of adult mollusks near the coast (Archambault et al., 1998). The oceanographic conditions along the coast may have been generally favorable for upwelling to occur. Physico-chemical information was consistent with a weak upwelling, and may explain the elevated densities in the 150 – 200 m layer in the coastal station.

Cluster analysis showed three clusters of samples (Figure 6) grouped on the basis of similarities in zooplankton species assemblages: the deeper waters from 200 – 400 m in the coast, the deeper layer (200 – 400m) in the offshore station, and the thermocline layer up to the surface (0 – 200m) in both stations. The deeper coastal layer was characterized mainly by relatively high abundance of the ubiquitous groups of zooplankton, like the Calanidae and Heterorhabdidae families of calanoids, Oncaeid cyclopoids, ostracods and the pelagic mollusk, *Hydromyles*. Calanids and oncaeids are among the more abundant copepod families and they are found in the epipelagic down to the mesopelagic layer, while heterorhabdids are more commonly found in deeper water (Boxshall and Halsey, 2004). Ostracods in tropical waters are abundant in the mesopelagic layer especially in marginal seas and coastal areas of the ocean (Vinogradov, 1968). In this study, these zooplankton groups were also present in the thermocline layer but in lower densities. This suggests that these taxa are those that can tolerate the environmental conditions of deeper water in the coastal station.

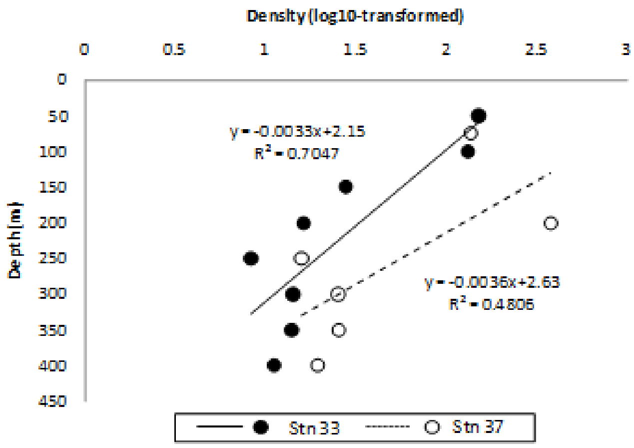


Figure 4. Linear regressions of $\log_{10}$ –transformed density data in stations 33 and 37, where *x* = depth (independent) and *y* = density (dependent) in the equation. Note: open circles and broken line for station 37; filled circles and solid line for station 33.

Meroplankton groups such as gastropods, pagurids, echinoderms, bivalves and cirripedes, on the other hand were more abundant in the thermocline layer. Low to moderate frequencies of these meroplankton characterize the more productive surface layer especially with their high abundance in the 0 – 50 m layer offshore (Table 2). A larger group of zooplankton (including Scolecitrichidae, Corycaeidae, forams and mysids) was recorded in both the thermocline and the deep offshore clusters, but in somewhat higher abundances in the former.

CONCLUSIONS

The abundance values presented in this study are lower compared to other published data for the Sulu Sea or for other internal water basins in the Philippines (Table 4). Nishikawa et al. (2007) reported much higher densities (20 – 800 ind./m^3) for zooplankton in the central portion of the Sulu Sea, but showed peaks in the upper (< 200 m) layer similar to what was observed in the offshore and coastal stations in this study. A MOCNESS of the same dimensions and manufacturer was used by Nishikawa et al. (2007). Seasonal differences might also be discounted because Nishikawa's work was also done in November. Since it is not related to gear or to season, the difference might be related to the location of the stations surveyed in this study.

High ambient nutrient concentrations are not always observed in upwelling areas (Primavera et al. 2002). Upwelling generally leads to high nutrient concentrations in the surface, but high nutrient concentrations are consumed by high phytoplankton abundance. Chlorophyll information (Figure 3) showed higher concentrations along the coast and lower away from the coast. If there were upwelling, phytoplankton abundance could have been high and nutrients would have been used up quickly, resulting in relatively low concentrations. Under these circumstances, high zooplankton concentrations would be expected. However, if planktivores such as sardines, are also numerous in the area, predation rates may also be high such that ambient zooplankton concentrations are much reduced due to fast cropping rates. Hence, low zooplankton abundance alone need not indicate low productivity. Put in another way, high zooplankton abundance need not always be the case in productive areas. Thus, low abundance in this transect suggests that conditions in the study area are different from other locations in the Sulu Sea.

Table 4. Zooplankton densities reported for the internal waters of the Philippines. Note: DOT – double oblique tow; MOC – MOCNESS; HT – horizontal tow; VT – vertical tow.

Zooplankton	Reference	Gear Type	Density (ind./m^3)
Central Philippines	Campos et al. (2002)	VT (200um)	3012
Tawi-tawi	Campos (2004)	HT (335um)	244
Surigao	Campos (2004)	HT (335um)	477
Calamianes	Campos (2004)	HT (335um)	364
Sulu Sea	Nishikawa et al. (2007)	MOC (335um)	10 – 800
Sulu Sea	This study	DOT (335)	8 – 373

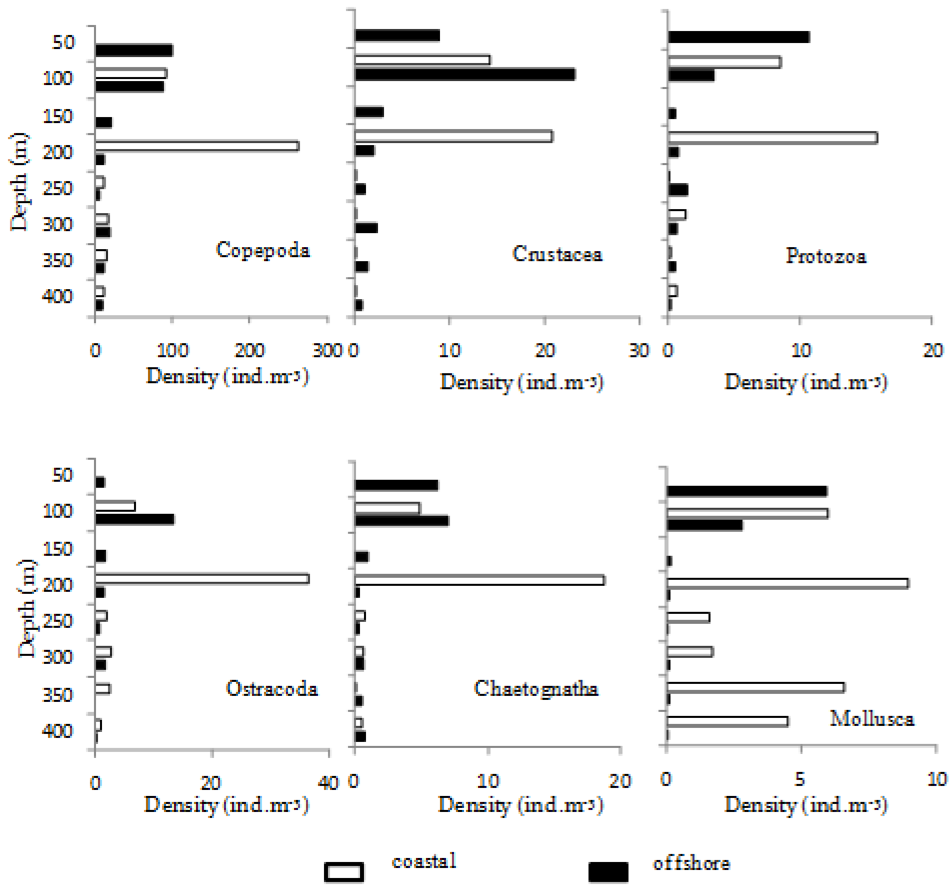


Figure 5. Vertical distribution of abundances of dominant zooplankton near the coast and offshore.

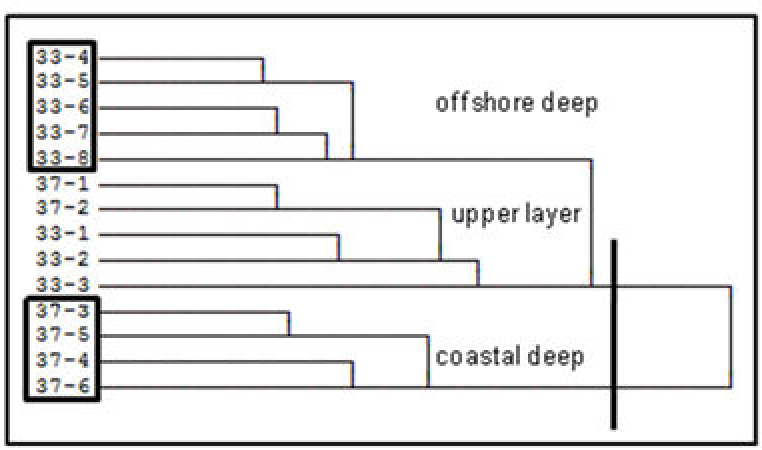


Figure 6. Clusters of samples showing similar assemblages of major zooplankton taxa. Samples form three groups: offshore deep, upper layer in both stations and the coastal deep.

Station 37 is located in a known upwelling area. Satellite images of sea surface color and temperature (Pullen et al., 2008) during the transect survey period, however, did not show elevated surface chlorophyll concentrations in this vicinity. On the other hand, the distribution of surface chlorophyll *a* concentrations along the transect showing somewhat higher values close to the coast is indicative of at least weak upwelling. High zooplankton concentration extending to deeper strata, along with a more abundant, but less diverse meroplankton assemblage closer to the coast are indicative of different processes influencing the above-thermocline layers along the coast. These results are not inconsistent with weak upwelling in the area.

The results of the study suggest that vertical mixing is more extensive close to the coast (consistent with upwelling area) and that this does not extend far (~70 km) from the coast, at least under conditions similar to what occurred during the present survey. There seems to be little (horizontal) mixing between the northwest coast of Zamboanga Peninsula and offshore waters, although this may differ under strong upwelling conditions. Oceanographic conditions near the coast may be conducive for upwelling that becomes intensified when all conditions are favorable. There is still a need to examine temporal variability (e.g., within seasons) in the intensity of upwelling and the different conditions leading to such.

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