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# Mesozooplankton composition and abundance in San Ildefonso Cape, Casiguran, Aurora, Northern Philippines

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**Abstract**. Mesozooplankton composition, diversity, abundance and their relation with the physico-chemical parameters of the waters during high and low tides in San Ildefonso Cape, Aurora Province, Philippines were compared. A total of 60 species belonging to 9 major groups were identified. Copepoda constituted the major bulk of the mesozooplankton community with *Paracalanus parvus*, *Corycaeus andrewsii*, *Oithona similis* and *Oncaea venusta* being the most abundant and widely distributed copepods in the said area. Using several diversity indices, high diversity in the mesozooplankton taxa was observed, but no differences were seen between the sampling stations and between the two tidal cycles. Likewise, the results of NPMANOVA revealed no significant differences ($p>0.05$) in mesozooplankton relative abundance between and within sampling stations between and during high and low tides. The results may imply that the level of mesozooplankton diversity and abundance did not fluctuate with changes in the tide levels and that mesozooplankton taxa were thus uniformly distributed in the waters of San Ildefonso Cape. Results of Canonical Correspondence Analysis revealed dissolved oxygen in influencing the mesozooplankton composition and abundance; however other factors (i.e. Kuroshio current) may also be important in shaping the community structure of mesozooplankton. Considering the importance of copepods as major component of the marine zooplankton and its function in marine food webs, the present records are therefore crucial in understanding the dynamics of marine ecosystems and are necessary for purposes of management and conservation of marine resources.

**Key Words**: Tropical copepods, community structure, high and low tides, Northern Philippines.

**Introduction**. Marine zooplankton comprised a large variety of different organisms which ranges from tiny flagellates up to giant jellyfish. Basically, they are catergorize based on the five size classes: (a) nanozooplantkon (2-20 μm), represented by heterotrophic nanoflagellates, (b) microzooplankton (20-200 μm), comprised by protozonas, eggs and early stages of crustaceans, (c) mesozooplankton (0.2-20 mm), represented by small hydromedusae, ctenophores, chaetognaths, appendicularians, doliolids, fish eggs and larvae, (d) macrozooplankton (2-20 cm) comprising larger hydromedusae, siphonophores, scyphomedusae, mysids, amphipods, euphausiids, salp, and (e) megazooplankton (20-200 cm) represented by jellyfish, pelagic tunicates, pyrosomes and chain-forming salps (Harris et al 2000).

The zooplankton are the most abundant constituents of the marine fauna that plays a pivotal position in the marine food webs (Poulet & Williams 1991; Kiorbe 1997) since they function as food for many marine faunistic assemblages such as the planktivorous fish, shrimps, crabs, chaetognaths and even jellyfish (Uye 2011). Among the marine zooplankton, copepods are the most familiar and dominant constitutent since they comprise around 55-95% of the total zooplankton abundance in the marine pelagic system (Longhurst 1985). Aside from this role, they can be considered as indicators of various water masses (Hwang et al 2006, 2007; Dur et al 2007) because they are sensitive to water mass properties, an important parameters that are the major factors influencing their spatial distribution and abundance (Hwang & Wong 2005; Hwang et al 2006; Alcaraz et al 2007). Many studies on the community structures of western Pacific mesozooplankton, particularly in Asian waters, has been well documented (Tseng et al 2013; Hsiao et al 2011; Ka & Hwang 2011; Hwang et al 2010; Tseng et al 2008; Dur et al 2007; Hwang et al 2007; Lee et al 2006; Lo et al 2004; Hsieh et al 2004; Hsieh & Chiu 2002; Noda et al 1998). However, this microfaunistic assemblage in San Ildefonso Cape, is still poorly represented. This is a crucial gap in the knowledge on tropical zooplankton, particularly in Asia, as San Ildefonso Cape faces the western Pacific Ocean and may have been influence by transport of large masses of water by the Kuroshio Current, one of the major ocean current in the world. Considering the whole marine food web and the economies of the coastal nations revolving around zooplankton, data on patterns of diversity, distribution and abundance must be expanded (Conway 2005). To address this gap, this study was carried out during high and low tides in order to investigate (1) the composition, diversity and abundance of mesozooplankton, (2) to measure the physico-chemical condition of the water and then (3) correlate the physico-chemical parameters of the water to the mesozooplankton diversity and abundance. By doing this, any future effects in diversity, whether due to natural, climate or human-induced changes, can be recognized so that proper policy and management decisions be formulated.

**Material and Method**. San Ildefonso, which extends 28.2 km long, is part of the 410 kilometers coastline of Aurora and is considered as the gateway to the Pacific Ocean (http://www.aurora.gov.ph/about-aurora/). Hence, the fact that the area is directly facing the west part of the Pacific Ocean made it highly vulnerable to different seasons and monsoon winds. A total of five sampling stations were positioned in the waters of San Ildefonso Cape (Figure 1) using a GPS (GPS map 76S, Garmin). The areas have typical semidiurnal tides with high and low waters in a lunar day of 24 hours. All hydrographic data and zooplankton samples were collected in each of these stations at high and low tides during spring tide in July 25, 2012. Hydrographic data, namely subsurface (50m depth) water temperature, pH, salinity, and dissolved oxygen, were measured “in situ” using the Oxical DO meter while salinity was estimated with the aid of a handheld refractometer (Atago, Japan). For total suspended solids, the gravitational filtration method was adopted. Zooplankton samples were collected in each of the 5 stations by vertical tows using a conical plankton net (length: 1.8m; mouth diameter: 0.45m; mesh size opening: 300µm) from 50 m depth to the surface. A flowmeter (Rigosha and Co., Ltd No 1687) was attached to the center of the net opening to measure the quantity of the water filtered. The zooplankton samples were immediately transferred into a properly labeled polyethylene bottles and preserved in 5% buffered formalin-seawater solution. Triplicate samples were collected in each sampling station. Since the plankton samples collected were not dense/rich with zooplankton, no splitting was done, instead the whole samples were used for counting. Using a Sedgewick-Rafter counting chamber cell, the zooplankton and copepods were counted until it reaches at least 300 individuals. Relative abundance of zooplankton and copepod was derived from the numerical counting of each zooplankton sample. The zooplankton and copepod individuals were sorted and identified to the nearest taxa possible using the standard works of Kasturirangan (1963), Owre & Foyo (1967), Yamaji (1962), Todd & Laverack (1991), Bradford-Grieve (1999ab), Mulyadi (2004) and Al-Yamani et al (2011).

Diversity indices were computed using Shannon-Weaner Index, Margalef Index and Menhinick index. Cluster analysis was used to deternine the major groupings of zooplantkon present between the five sampling stations between high and low tides. Canonical Correspondence Analysis (CCA) was employed to determine the physico-chemical parameters that influenced the relative abundance of zooplankton during high and low tides. Non-Parametric Multivariate Analyses of Variance (NPMANOVA) was used to determine the differences in zooplankton relative abundance between sites, within sites and between two tidal cycles. All statistical analyses were done using the software PAST version 2.17 (http://folk.uio.no/ohammer/past/) (Hammer et al 2001).

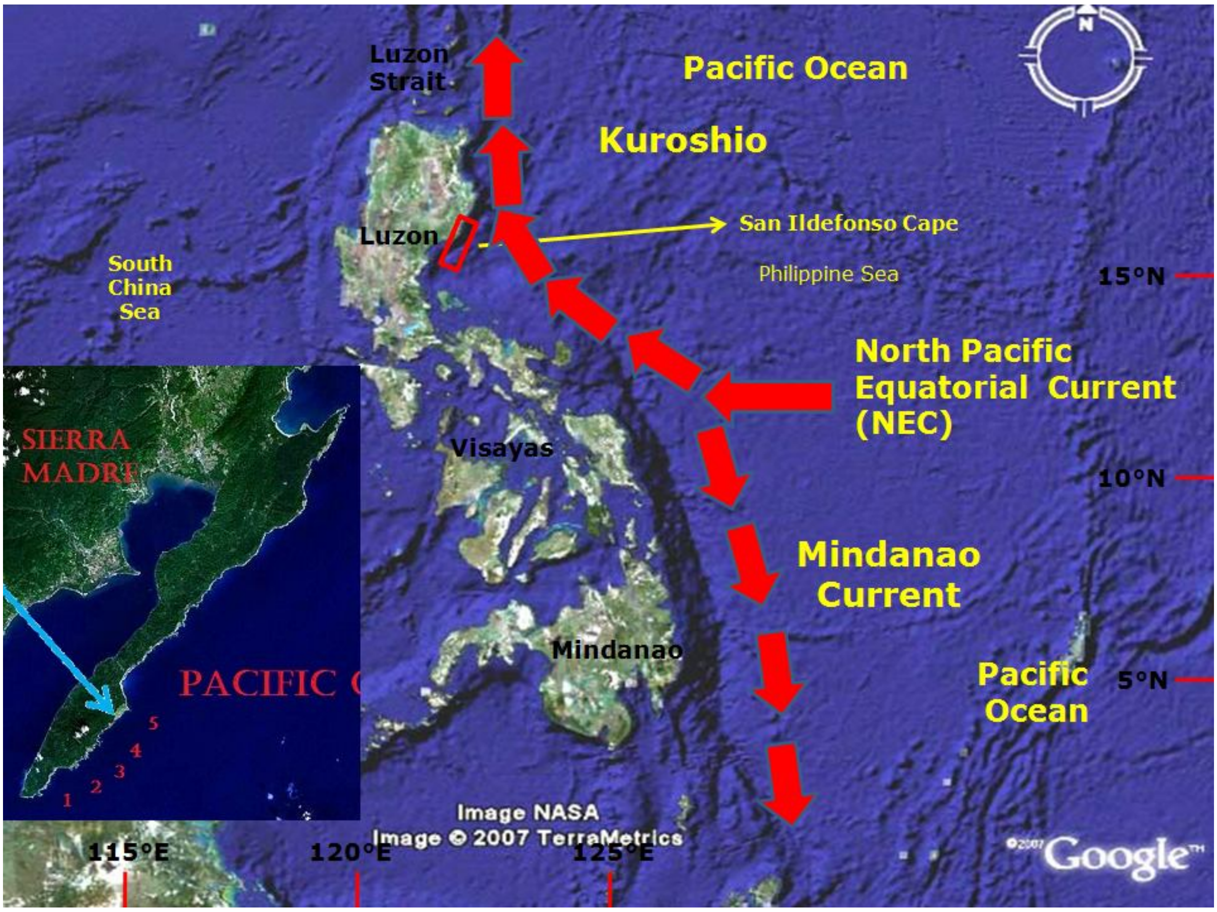


Figure 1. Map of the Philippines showing the regions where Kuroshio originates, with San Ildefonso Cape enclosed in a red rectangle. Inset is the map of San Ildefonso Cape, Casiguran, Aurora showing the geographical location of the five sampling stations where zooplankton samples were collected.

**Results and Discussion**. A total of 60 zooplankton taxa belonging to 9 major groups (Protozoa, Cnidarian, Annelida, Chaetognatha, Protochordata, Arthropoda, Mollusca, Echinodermata and Chordata) were identified during high tide and low tide in the five sampling stations in San Ildefonso Cape, Casiguran, Aurora (Table 1). This includes 30 species of Copepoda (21 from Calanoida, 6 from Poecilostomatoida, 2 from Cyclopoida and 1 from Harpacticoida); 4 species of Protochordata; 2 species each of Protozoa, Cnidaria (Siphonophore), Chaetognatha, Ostracoda; 1 species each of Decapoda, Cladocera, Amphipoda; 1 representative from Mysidacea and Euphausiacea; 10 larval forms and 2 Ichthyoplankters. Despite similarity in the number of zooplankton taxa recorded (60 for both tide cycles, Table 2), some changes in the composition were very apparent when the 2 tidal cycles were compared. For instance, *Metridia brevicauda*, a calanoid copepod, was found only during low tide, while *Lucifer hanseni*, a decapoda, was observed during high tide. Other than differences in these 2 arthropoda, the rest of the 58 identified zooplankters were observed during the 2 tidal cycles. Out of the 9 major groups, the Arthropoda, particularly crustaceans, was the major component of the zooplankton community in all sampling stations during high and low tides and comprises more than 76% of the total zooplankton population. However, the remaining 8 groups (Protozoa, Cnidarian, Annelida, Chaetognatha, Protochordata, Mollusca, Echinodermata and Chordata) were low in numbers (<20%).

Table 1

Composition and species richness of zooplankton in the five sampling stations during high and low tides in San Ildefonso Cape, Casiguran, Aurora, Philippines

| *Zooplankton Taxa* | *High Tide* | | | | | *Low Tide* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | *1* | *2* | *3* | *4* | *5* |
| Holoplankton | | | | | | | | | | |
| **Protozoa** | | | | | | | | | | |
| *Acantharia* | - | - | - | + | - | + | - | + | + | + |
| *Globigerina* | + | + | + | + | + | + | + | + | + | + |
| **Cnidaria** | | | | | | | | | | |
| *Muggiae* | + | + | + | + | + | + | + | + | + | + |
| *Diphyes* | - | + | - | + | - | + | + | + | - | + |
| **Chaetognatha** | | | | | | | | | | |
| *Sagitta crassa* | + | + | + | + | + | + | + | + | + | + |
| *Sagitta maxima* | + | + | + | + | + | + | + | + | + | + |
| **Protochordata** | | | | | | | | | | |
| *Oikopleura* spp. | + | + | + | + | + | + | + | + | + | + |
| *Oikopleura dioica* | + | + | + | + | + | + | + | + | + | + |
| *Fritillaria* | - | + | + | + | + | + | + | + | + | + |
| *Doliolum* | + | - | + | + | + | + | + | + | + | + |
| **Arthropoda** | | | | | | | | | | |
| **Copepoda** | | | | | | | | | | |
| **Calanoida** | | | | | | | | | | |
| *Temora discaudata* | + | + | + | + | + | + | + | + | + | + |
| *Temora stylifera* | + | + | - | + | - | + | + | + | - | + |
| *Calocalanus pavo* | + | + | + | + | + | + | + | + | + | + |
| *Candacia catula** | + | + | + | + | + | + | + | + | + | + |
| *Canthocalanus pauper* | + | - | - | + | - | + | - | + | + | + |
| *Centropages furcatus* | + | + | + | + | + | + | + | + | + | + |
| *Clausocalanus arcuicornis** | + | + | + | + | + | + | + | + | + | + |
| *Acrocalanus gracilis** | + | + | + | + | + | + | + | + | + | + |
| *Eucalanus subcrassus* | - | + | - | - | - | + | + | + | - | + |
| *Eucalanus subtenuis* | + | + | + | + | + | + | + | + | + | + |
| *Undinula vulgaris** | + | + | + | + | + | + | + | + | + | + |
| *Paracalanus parvus** | + | + | + | + | + | + | + | + | + | + |
| *Acartia negligens** | + | + | + | + | + | + | + | + | + | + |
| *Acartia erythria* | + | + | + | + | + | + | + | + | + | + |
| *Labidocera truncata* | + | - | - | + | - | + | - | + | + | - |
| *Calanopia elliptica* | + | + | + | + | + | + | + | + | + | + |
| *Metridia brevicauda* | - | - | - | - | + | - | - | - | - | - |
| *Euchaeta* sp. * | + | + | + | + | + | + | + | + | + | + |
| *Tortanus forcipatus* | + | - | - | - | - | + | - | - | - | - |
| *Lucicutia aurita* | + | + | + | + | + | + | - | + | + | + |
| **Cyclopoida** | | | | | | | | | | |
| *Oithona similis** | + | + | + | + | + | + | + | + | + | + |
| *Oithona rigida** | + | + | + | + | + | + | + | + | + | + |
| **Poecilostomatoida** | | | | | | | | | | |
| *Copilia mirabilis* | + | + | + | + | + | + | + | + | + | + |
| *Corycaeus lubbocki* | - | + | + | + | + | + | + | + | + | + |
| *Corycaeus andrewsii** | + | + | + | + | + | + | + | + | + | + |
| *Oncaea media** | + | + | + | + | + | + | + | + | + | + |
| *Oncaea venusta** | + | + | + | + | + | + | + | + | + | + |
| *Sapphirina intestinata* | + | + | + | + | + | + | + | + | + | + |

| *Zooplankton taxa* | *High Tide* | | | | | *Low Tide* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | *1* | *2* | *3* | *4* | *5* |
| **Harpacticoida** | | | | | | | | | | |
| *Micrositella norvegica* | + | - | - | - | + | + | + | + | + | - |
| **Mysidacea** | + | + | + | + | + | + | + | + | + | + |
| **Euphausiacea** | + | + | - | + | + | + | - | + | + | + |
| **Cladocera** | | | | | | | | | | |
| *Evadne* | + | + | + | + | - | + | - | + | + | + |
| **Amphipoda** | | | | | | | | | | |
| *Hyperia* | - | + | + | + | + | + | + | + | + | + |
| **Ostracoda** | | | | | | | | | | |
| *Conchoecia* | + | + | + | + | + | + | - | + | - | - |
| *Cypridina* | + | + | + | + | + | + | + | + | + | + |
| **Decapoda** | | | | | | | | | | |
| *Lucifer hanseni* | + | - | + | - | - | - | - | - | - | - |
| **Mollusca** | | | | | | | | | | |
| *Creseis* | + | + | + | + | + | + | + | + | + | + |
| **Meroplankton/Larval forms** | | | | | | | | | | |
| **Echinodermata** | | | | | | | | | | |
| Echinopluteus | + | + | + | + | + | + | + | + | + | + |
| **Cnidaria** | | | | | | | | | | |
| Hydromedusae | + | + | + | + | + | + | + | + | + | + |
| Leptomedusae | + | + | + | + | + | + | + | + | - | + |
| **Annelida** | | | | | | | | | | |
| Polychaete | + | + | + | - | + | + | + | + | + | + |
| **Mollusca** | | | | | | | | | | |
| Gastropod juvenile | + | + | + | + | + | + | + | + | - | + |
| Lamellibranch larvae | + | + | - | + | + | - | - | - | + | + |
| **Arthropoda** | | | | | | | | | | |
| Copepoda nauplius | | | | | | | | | | |
| **Decapoda** | | | | | | | | | | |
| Crab zoea | + | + | + | + | + | + | + | + | + | + |
| Megalopa | + | - | - | - | - | - | + | - | - | - |
| **Stomatopoda** | | | | | | | | | | |
| *Squilla* larvae | + | + | + | + | - | + | + | + | + | - |
| **Ichthyoplankters** | | | | | | | | | | |
| **Chordata** | | | | | | | | | | |
| Fish egg | + | + | + | + | + | + | + | + | + | + |
| Fish larvae | + | + | + | - | + | + | - | - | - | - |
| **Total number of individuals** | 54 | 51 | 47 | 53 | 49 | 57 | 49 | 55 | 50 | 51 |
| **Grand total number of individuals** | | | **59 (HT)** | | | | | **59 (HT)** | | |

Legend: + presence; – absence; HT-High Tide; LT-Low Tide *copepod species present in all sampling stations

The importance of crustacean zooplankters in terms of forming the bulk of abundance in the mesozooplankton community was also strongly emphasized and reported in other bodies of coastal, neritic and oceanic waters (Tseng et al 2013, 2012; Jagadeesan et al 2013; Ka & Hwang 2011; Ogbeibu & Oribhabor 2011; Fernandes & Ramaiah 2009; Etile et al 2009; Robin et al 2009; Onyema & Ojo 2008; Yoshida et al 2006; Webber et al 2005; Uy et al 2006; Irigoien et al 2002; Relox et al 2000; Noda et al 1998; Osore et al 1997; Champalbert 1996; Wiafe & Frid 1996). Crustacean zooplankters are the key organisms in aquatic ecosystems because they represent an important link in the marine food webs. They transport materials and energy from the primary production of phytoplankton to higher level of consumers, i.e. many fish species in the oceans (Uye 2011; Irigoien et al 2002; Kiorbe 1997). Of these arthropods (Figure 2), the copepods were the most dominant and abundant constituents in both high and low tides, accounting to more than 75% of the total arthropoda population, whereas the rest of the arthropod members attained less than 2% only. As to the copepod-groups, Calanoida was the most species-rich (21) representing 55% of the total copepod abundance on average for all stations during the two tidal cycles. This is followed in order by Poecilostomatoida (6) which represents more than 25%, Cyclopoida (2) accounted to more than 10% and Harpacticoida (1), being the least abundant, was less than 1%.

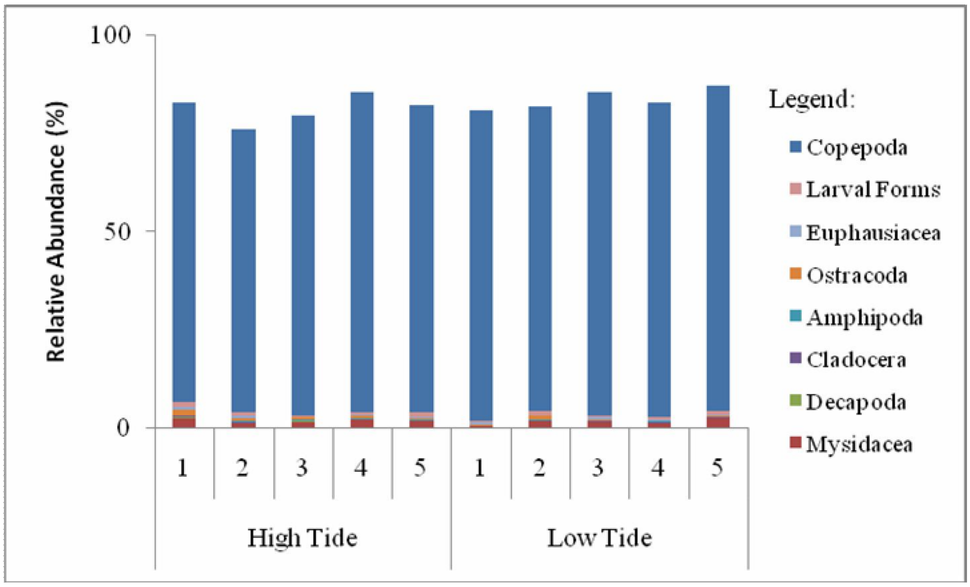


Figure 2. Relative abundance (%) of the members of arthropoda in each sampling stations during high tide and low tide in San Ildefonso Cape, Casiguran, Aurora, Philippines.

Similarly, looking at the relative abundance of these copepod groups in each of the sampling stations during the 2 tidal cycles (Figures 3 a-b), Calanoida still predominated. The dominance of Copepoda, in particular the calanoids, in constituting the major bulk of abundance in the community is in agreement with earlier reports (Tseng et al 2013, 2012; Jagadeesan et al 2013; Johan et al 2013; Chou et al 2012; Ka & Hwang 2011; Maiphae & Sa-ardat 2011; Hsiao et al 2011; Chen et al 2010; Jitchum & Wongrat 2009; Tseng et al 2008, 2009; Hwang et al 2007; Dur et al 2007; Lee et al 2006; Rezai et al 2004; Lo et al 2004; Hsieh et al 2004; Uy et al 2006; Hsieh & Chiu 2002) who demonstrated calanoid copepods to be the most dominant contributors in the zooplankton community. Mauchline (1998) added that calanoid species are numerous from 0-100m depth layer in oceanic waters and are even the most abundant taxa in waters shallower than 100m in coastal, neritic and oceanic waters (Tseng et al 2013; Yoshida et al 2006; Irigoien et al 2002). The dominance and abundance of copepods in the marine ecosystem is not surprising since they were known for many years to dominate the pelagic realms of the ocean (Schminke 2007; Lopes et al 2007; Miyashita et al 2009). The keys to their successful existence and dominance in a much crowded marine environment are owed to the intrinsic features of their anatomy, physiology, behavior and life cycle (Schminke 2007). Therefore, the role of planktonic copepods among zooplankton assemblages could not be ignored despite its miniature size since they contributed more than 80% of the plankton community and are important food sources of fish (Mahjoub et al 2011; Dahms & Hwang 2007) and even jellyfish (Uye 2011). Due to their importance, they likely play a pivotal role in the transfer of matter and energy in the marine ecosystem. Despite the dominance of calanoids in terms of numerical and species richness, other dominant copepod species always included some cyclopoids (*Oithona similis* and *O. rigida*) and poecilostomatoids (*Corycaeus andrewsii*, *Oncaea venusta*, *Onc. media*).

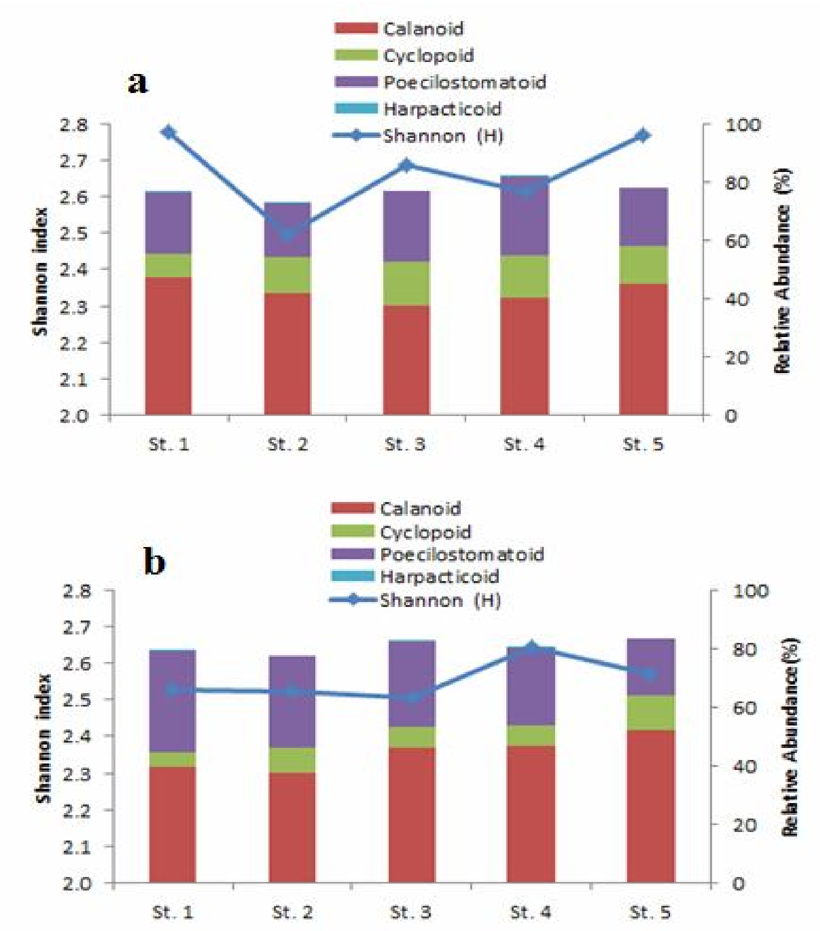


Figure 3. Diversity profile and relative abundance of copepod-groups in each sampling station during (a) high tide and (b) low tide in San Ildefonso Cape, Casiguran, Aurora, Philippines.

Moreover, out of the dominant copepods, *Paracalanus parvus* was the most abundant species and represents 22.08% and 15.84% of the total copepod population during high and low tides, respectively. Other most common and abundant species representing more than 2% of the population during high tide were *O. similis* (14.03%), *C. andrewsii* (11.63%), *Onc. venusta* (8.85%), *Acrocalanus gracilis* (7.37%), *Acartia negligens* (5.34%), *Onc. media* (4.32%), *Undinula vulgaris* (3.66%), *Euchaeta* sp. (3.42%), *Clausocalanus arcuicornis* (2.98%) and *Candacia catula* (2.63%). At low tide, dominant and abundant species were *C. andrewsii* (13.07%), *Onc. venusta* (11.86%), *O. similis* (8.50%), *A. gracilis* (8.24%), *C. arcuicornis* (7.36%), *Onc. media* (6.04%), *Undinula vulgaris* (4.33%) and *A. negligens* (4.00%). On average for all sampling stations, these dominant copepod species contributed about 88.84% and 85.61% of the total copepod population during high and low tides, respectively. Basically, these species were also present in all five sampling stations during the two tidal cycles (Table 1, as noted by an asterisk). To compare the relative abundance of individual copepod species between the five sampling stations during high and low tides, NPMANOVA (Non-Parametric Multivariate Analysis of Variance) did not show any significant differences ($p>0.05$). This would imply that the distribution of copepods did not vary all throughout the five sampling stations during the two tidal cycles. The reasons for these species' high abundance and frequent occurrence are their widely distribution around the worlds' oceans, being thermophilic, euryhaline, and having diverse feeding habits. In particular, the presence of *P. parvus*, which is the most abundant and widely occurring calanoid along San Ildefonso Cape, can be attributed to the following reasons: (1) it is cosmopolitan in distribution (Montu & Goleden 1998), being common in warm and temperate waters (Takahasi & Hirakawa 2001; Chen et al 1974; Chen & Zhang 1965);

(2) with variable ecological affinities to temperature (thermophilic) and salinity (euryhaline); (3) being widely recorded in the coastal, neritic and oceanic waters (Maiphae & Sa-ardat 2011; Vukanic 2010; Peterson et al 2002; Noda et al 1998; Stephen 1984; Chen & Zhang 1974; Chen et al 1965); and (4) able to shift from being herbivorous to omnivorous (Hafferssas & Seridiji 2010) and opportunistic species (Legendre & Legendre 1984). Peterson et al (2002) reported that *P. parvus* is a subtropical neritic species, which is generally found in association with coastal warm-water species. Aside from *P. parvus*, other calanoids viz. *Acr. gracilis*, *Ac. negligens*, *U. vulgaris*, *C. arcuicornis* and *C. catula*, which were included in the list of abundant copepod species in the present study, were likewise reported to be widely distributed in the coastal, neritic and oceanic waters (Hsieh et al 2004; Noda et al 1998; Maiphae & Sa-ardat 2011; Vukanic 2010; Dur et al 2007; Lo et al 2004; Chihara & Murano 1997; Campaner 1985). Other copepod-groups, i.e. the cyclopoid and poecilostomatoids, such as *O. similis*, *C. andrewsii*, *Onc. venusta* and *Onc. media*, were also predominant in San Ildefonso Cape. According to Nishida (1985), *O. similis* are cosmopolitan in the epipelagic waters, being euryhaline and eurythermal in nature when compared to other copepod species in coastal (Maiphae & Sa-ardat 2011) to oceanic and tropical to temperate to polar waters. Moreover, they are also broadly omnivorous by consuming upon different food sources viz. phytoplankton, copepod nauplius, ciliates and heterotrophic dinoflagellates (Nakamura & Turner 1997). Thus, the ability of this copepod to exploit the lower portion of the food size spectrum, which is more coupled to the microbial loop than to phytoplankton blooms, may contribute to *O. similis*' ability to maintain an almost-continuously stable population (Turner 2004). In addition, the low respiration rates of *O. similis* (Marshall & Orr 1966; Nakamura & Turner 1997 c.f. Turner 2004) and its infrequent intermittent movement (Paffenhofer 1983; Hwang & Turner 1995 c.f. Turner 2004) might result in energy savings that can be channeled into reproduction. Another abundant poecilostomatoid is *Onc. venusta* which predominated in all sampling stations. Several studies observed this copepod to be commonly encountered in coastal, neritic and oceanic waters especially in the Northwest Pacific Ocean (Hsieh et al 2004; Noda et al 1998; Chen & Zhang 1974; Chen et al 1965), Caribbean waters (Webber et al 2005), and Southern Brazil (Campaner 1985). According to earlier documentations, its diverse feeding preferences include toxic dinoflagellates (Turner & Tester 1997; Wu et al 2004) to marine snow (Alldredge 1972) and therefore can shift from being an omnivore (Turner 1986) to detritivore (Yamaguchi et al 2002). Moreover, the species can decrease respiratory losses by changing their mode of existence from pelagic to a pseudopelagic mode (Nishibe & Ikeda 2008). Hence, the wide occurrence, diverse feeding habits as well as respiratory adaptation of *Onc. venusta* over a wide latitudinal range and hydrographical regime seems to contribute to their successful colonization and dominance in San Ildefonso Cape as suggested by Fernandes & Ramaiah (2009). Thus, the common and abundant copepods in San Ildefonso Cape might have employed a variety of strategies to maximize reproduction and survival in order to overcome likely substantial losses due to predation as suggested by Turner (2004).

The water quality parameters assessed in the five sampling stations have shown variations (Figures 4 a-c). For example, the mean water temperature during high tide was highest in station 3 and lowest in station 1 with mean values of 30.07°C and 29.33 °C, respectively (Figure 4a). During low tide, the mean water temperature was high in station 5 and still low in station 1 with mean values of 20.00°C and 28.83 °C, respectively. Variations in the subsurface water temperatures among the stations were due to differences in light intensity since temperatures were measured at different times of the day. During high tide, subsurface water temperatures were taken around 9:25–9:40 and 10:30-10:49 in the morning at stations 1 and 3, respectively. During low tide, these were measured late in the afternoon (5:03–5:17 pm in station 1 and 3:05–3:22 pm in station 5). For salinity values, all the five sampling stations have the same salinity

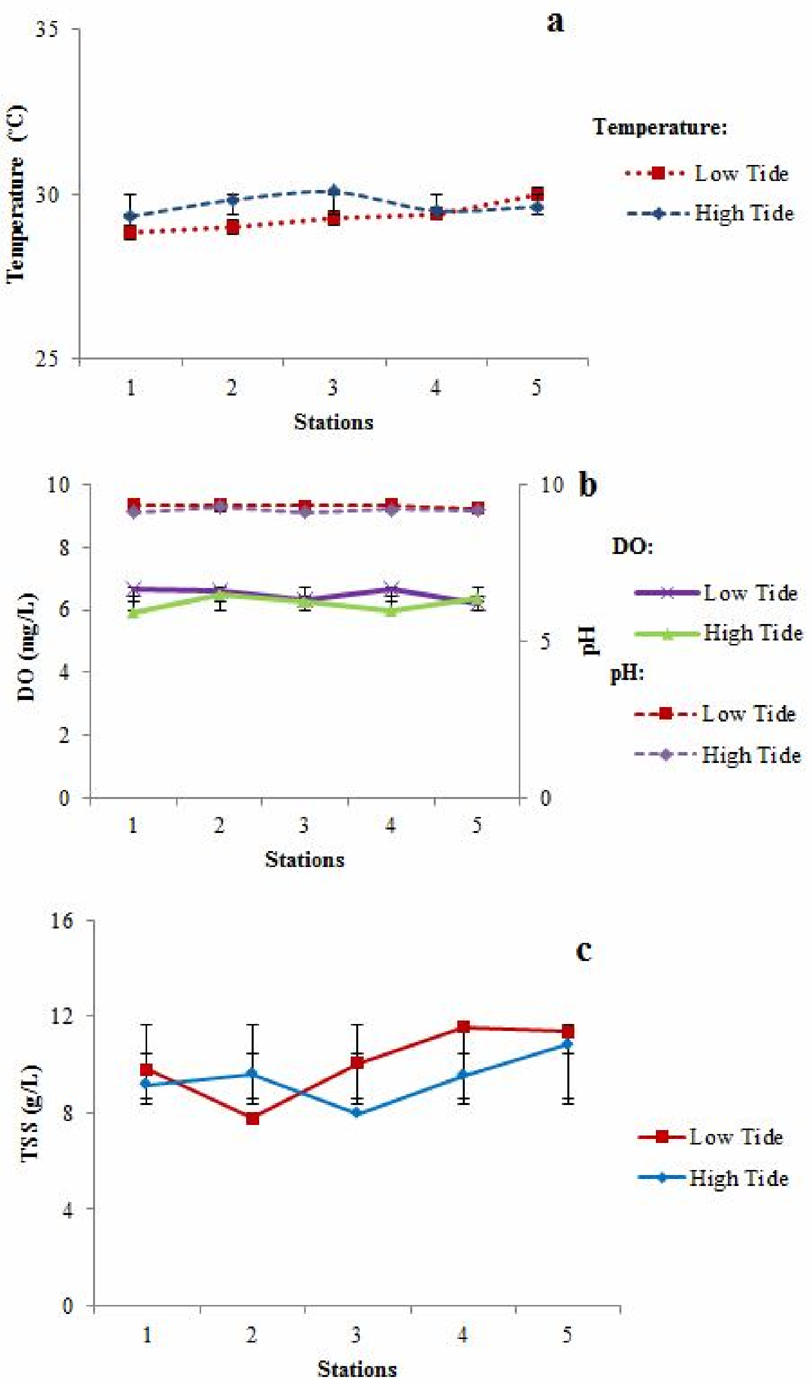


Figure 4. Mean values of (a) water temperature (°C), (b) DO (mg/L), and (c) TSS (g/L) in the five sampling stations during high and low tides in San Ildefonso Cape, Casiguran, Aurora, Philippines.

values of 35 ppt. This is expected since San Ildefonso Cape is located facing the western Pacific Ocean where waters are more saline. Dissolved oxygen (DO) is the amount of gaseous oxygen dissolved in water. It is an important parameter in aquatic life as it is required for metabolism of aerobic organisms and also influences inorganic chemical reactions (Puyate & Rim-Rukah 2008). High DO values (Figure 4b) were noted in station 2 (6.48 mgL$^{-1}$) and 4 (6.68 mgL$^{-1}$) during high and low tides, respectively. On the other hand, low DO values were observed in station 1 (5.92 mgL$^{-1}$) during high tide and in station 5 (6.23 mgL$^{-1}$) during low tide. High alkaline pH range values (9.12-9.36) have been recorded in all stations for both high and low waters (Figure 4b), much higher than the slightly alkaline seawater (pH 7.5-8.5). It has been reported that the alkaline pH values are almost always determined by the buffering effect of dissolved salts or seawater (Schmieglow 2004; Costa et al 2009) and from a high concentration of free $CO_2$, carbon-based mineral molecules suspended in the water, specifically calcium carbonate that comes from rocks like limestone or can be leached from calcite in the soil (George et al 2012). Turbidity (total suspended solids) is a measure of the attenuation of light in the water column and can be caused by the light adsorption properties of the water, the number of planktonic organisms in the water, and with the amount of suspended particulate organic and inorganic matter (Parr et al 1998). It has been stressed out that suspended particulate matter is often the primary cause of turbidity of the water (Dawes 1981). TSS value (Figure 4c) during high tide was highest in station 5 (10.85 $gL^{-1}$) but lowest in station 3 (7.95 $gL^{-1}$). During low tide, station 4 (11.55 $gL^{-1}$) showed highest values, whereas lowest value was observed in station 2 (7.80 $gL^{-1}$). Despite variations in the water quality parameters as reflected in Figures 4 a-c, the values are within the range for any marine faunistic assemblage to thrive and be fairly abundant (DENR 1990).

The level of the diversity and species richness of zooplankton taxa in San Ildefonso waters between high tide and low tide revealed no difference in the number of taxa as well as the diversity of zooplankton, wherein both tidal cycles have the same species richness (59) and high species diversity values of 3.2 as reflected in the Shannon-Weaver (H'). On the other hand, looking at the level of species richness of zooplankton between stations (Table 2), it can be seen that difference in the number of taxa was minimal only. These differences range from 0-6 between stations, with station 1 exhibiting the highest number of taxa (60), while stations 2, 4 and 5 showed lowest values (54). Moreover, when comparing the diversity of zooplankton taxa between stations, results did not exhibit any difference with each other as reflected in its high H' values (ranges: 3.1-3.2). Since copepods constituted the major bulk of the total zooplankton population, the levels of copepod diversity were therefore calculated. Data revealed high levels of copepod diversity values (H' ranges from 2.4-2.7) in each sampling stations during and between high tide (Figure 3a) and low tide (Figure 3b), while the number of species ranges between 26 and 30 in both tidal cycles. The result further supports the dominance of copepod groups as major contributor in the mesozooplankton community. Basically, very high diversity values of mesozooplankton as well as copepod species were prominent in the present study with very minimal variations observed among the different sampling stations and between the two tidal cycles. Several studies had shown that the levels of diversity for mesozooplankton, particularly those of the copepods, were usually high in oceanic waters (H'values ranged: 2.50-5.16) when compared to those in the neritic and coastal zones (H' values <1.5) (Tseng et al 2013; Marin & Delgado 2009; Fernandes & Ramaiah 2009; Tseng et al 2008; Lee et al 2006; Hsieh et al 2004; Yang et al 1999; Lopes et al 1999; Noda et al 1998; Shih & Chin 1998; Champalbert 1996; Kang & Hong 1995). In the case of San Ildefonso Cape, the values recorded (H' ranges from 2.4-2.7) are within the ranges reported for oceanic waters. The high diversity, high evenness and the narrow range in variations of species richness in the study area could be due to the relatively homogenous and stable hydrographic conditions in the said sampling stations (viz. physical and chemical parameters of the waters) as similarly suggested by Lee et al (2006). The high evenness values recorded when comparing the zooplankton taxa as well as the copepod species among sampling stations and between the two tidal cycles further justifies the observed high diversity values (H') and the low dominance indices. It has been reported that high diversity with low dominance values are common in oligotrophic, stress-free environment and low levels of ecological stress for marine microfauna and flora communities (Kouwenhoven 2000; Drinia et al 2004; Lacuna et al 2013). Generally, the diversity index is a suitable criterion for water quality (Balloch et al 1976; Gharib & Dorgham 2006) and its value is related to the disturbance of environment.

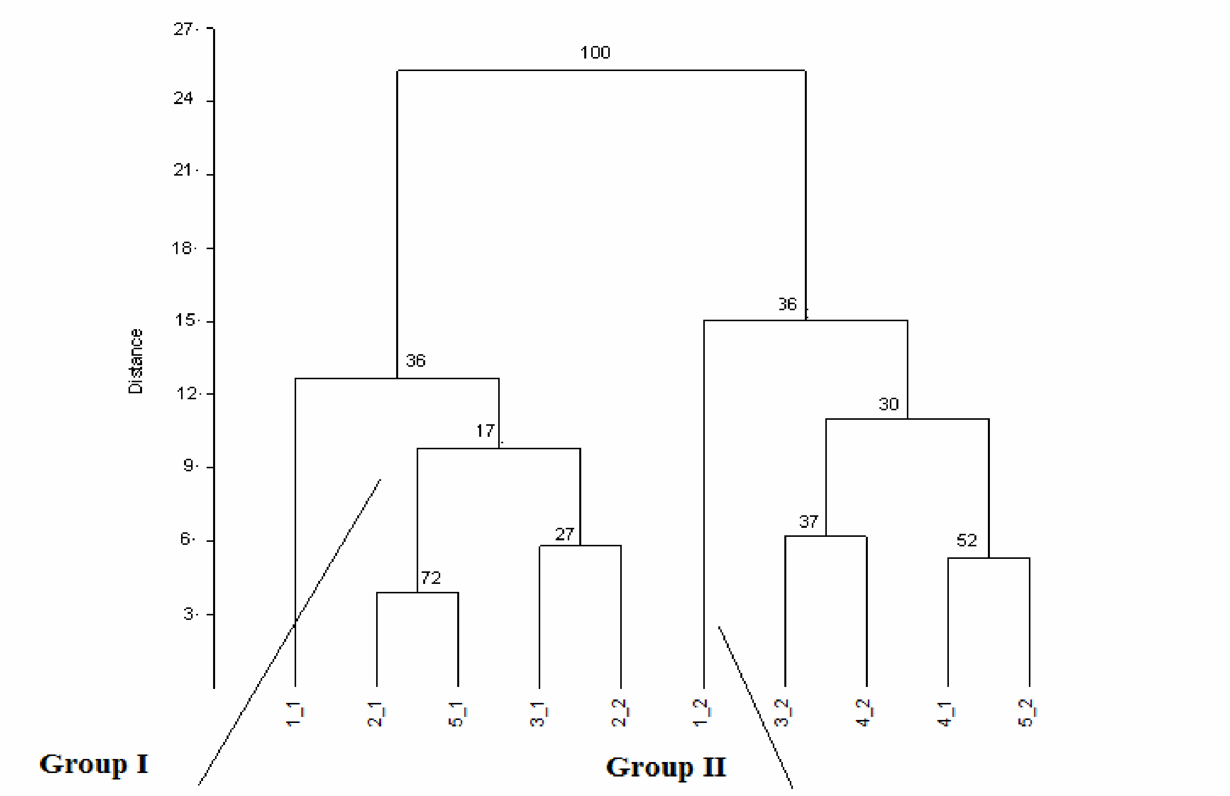
Table 2

Diversity profiles of zooplankton taxa in each sampling stations in San Ildefonso Cape, Casiguran, Aurora, Philippines

| *Diversity* | *Stations* | | | | |
|---|---|---|---|---|---|
| *Index* | *1* | *2* | *3* | *4* | *5* |
| Taxa (S) | 60 | 54 | 56 | 54 | 54 |
| Individuals | 2344 | 2411 | 2304 | 2243 | 2243 |
| Dominance (D) | 0.05851 | 0.06775 | 0.06235 | 0.06501 | 0.0646 |
| Simpson (1-D) | 0.9415 | 0.9323 | 0.9377 | 0.935 | 0.9354 |
| Shannon (H) | 3.288 | 3.185 | 3.186 | 3.166 | 3.199 |
| Evenness (e^H/S) | 0.4466 | 0.4477 | 0.4319 | 0.439 | 0.454 |
| Brillouin | 3.232 | 3.134 | 3.133 | 3.112 | 3.146 |
| Menhinick | 1.239 | 1.1 | 1.167 | 1.14 | 1.14 |
| Margalef | 7.603 | 6.806 | 7.104 | 6.869 | 6.869 |
| Equitability (J) | 0.8031 | 0.7985 | 0.7914 | 0.7936 | 0.802 |
| Fisher_alpha | 11.22 | 9.802 | 10.35 | 9.961 | 9.961 |
| Berger-Parker | 0.1301 | 0.1717 | 0.1367 | 0.14 | 0.1699 |
| Chao-1 | 61 | 54 | 59.33 | 54 | 60 |

Thus, if overall diversity is used as a measure of ecosystem stability, the highly diverse zooplankton community structure observed in San Ildefonso Cape can be used as a basis in saying that the area is considered as a stable marine ecosystem that host and cater diverse marine faunal and floral assemblages.

In order to know if zooplankton species and their abundances are similar between the five sampling stations during high and low tides, cluster analysis using Ward's method was employed. The dendrogram results (Figure 5) showed the stations that are similar on the basis of species composition and abundance. The presence of two major groups or clusters that more or less separates the two tidal cycles were apparent. Group I comprises of stations 1,2,3,5 at high tide and station 2 at low tide. Group II consists of stations 1,3,4,5 at low tide and station 4 at low tide. The dominant species that occurred in Group I were *P. parvus, C. andrewsii, O. similis, Onc. venusta, Onc. media, Acr. gracilis*, *Ac. negligens, Globigerina, U. vulgaris* and *Sagitta crassa*. The abundant species in Group II were *C. andrewsii, P. parvus, Onc. venusta, Acr. gracilis*, *Clausocalanus arcuicornis, O. similis, U. vulgaris, Ac. negligens, Globigerina and Onc. media*. It should be noted that only stations 2 and 4 did not separate according to tide levels, but instead clustered in one group (viz. Group I: station 2 at high tide and low tide; Group II: station 4 at high tide and low tide). Nonetheless, the 2 clusters, viz. Groups I and II, consisted of almost the same zooplankton community structure, except for the dominance of a chaetognath, *S. crassa* that is prevalent in Group I, and *C. arcuicornis* in Group II. It is believed that the presence of *S. crassa* may have been brought along by the incoming high water during high tide from the neighboring open seas (i.e. Taiwan Strait, Japan Sea and China Sea) via ocean current. The results may suggest that the mesozooplankton taxa were uniformly distributed by the alteration of high and low tides in the five sampling stations. In fact, most of the copepod species identified in the present study were also recorded in the northwestern Pacific Ocean (Tseng et al 2013, 2012; Ka & Hwang 2011; Hsiao et al 2011; Hwang et al 2010; Lee et al 2009; Tseng et al 2008; Hwang et al 2007; Dur et al 2007; Lee et al 2006; Hsieh et al 2004; Lo et al 2004; Hsieh & Chiu 2002; Noda et al 1998) and northern Pacific equatorial waters (Grice 1962). Since San Ildefonso Cape is an open sea that face the western Pacific Ocean, total



**Group I**

| Taxa | High Tide | | | | Low Tide |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 5 | 2 |
| *Acrocalanus gracilis* | 6.55 | 6.67 | 2.67 | 5.41 | 4.34 |
| *Undinula vulgaris* | 5.11 | 2.12 | 2.85 | 2.75 | 3.91 |
| *Paracalanus parvus* | 18.24 | 17.74 | 17.36 | 19.82 | 16.60 |
| *Acartia negligens* | 4.32 | 4.39 | 3.67 | 4.42 | 3.40 |
| *Oithona similis* | 6.22 | 11.45 | 13.05 | 10.25 | 8.59 |
| *Corycaeus andrewsii* | 12.70 | 6.43 | 8.60 | 7.01 | 11.55 |
| *Oncaea media* | 2.73 | 2.97 | 3.80 | 3.52 | 5.87 |
| *Oncaea venusta* | 4.52 | 5.68 | 8.32 | 6.68 | 10.25 |
| *Globigerina* | 3.26 | 4.27 | 4.39 | 3.00 | 2.92 |
| *Sagitta crassa* | 2.12 | 2.09 | 2.16 | 3.24 | 2.80 |

**Group II**

| Taxa | LowTide | | | | High Tide |
|---|---|---|---|---|---|
| | 1 | 3 | 4 | 5 | 4 |
| *Clausocalanus arcuicornis* | 4.89 | 9.80 | 6.66 | 7.54 | 7.50 |
| *Acrocalanus gracilis* | 8.31 | 7.28 | 6.96 | 6.93 | 6.32 |
| *Undinula vulgaris* | 3.74 | 3.88 | 1.25 | 2.17 | 3.65 |
| *Paracalanus parvus* | 7.12 | 9.69 | 11.60 | 13.91 | 16.36 |
| *Acartia negligens* | 2.52 | 3.51 | 3.65 | 5.01 | 1.78 |
| *Oithona similis* | 3.82 | 6.28 | 12.91 | 8.97 | 6.71 |
| *Corycaeus andrewsii* | 13.26 | 10.81 | 10.18 | 8.53 | 8.08 |
| *Oncaea media* | 8.38 | 3.43 | 3.58 | 1.84 | 4.43 |
| *Oncaea venusta* | 8.75 | 11.43 | 9.03 | 6.15 | 10.98 |
| *Globigerina* | 2.99 | 2.89 | 3.58 | 2.40 | 4.59 |

Figure 5. Cluster diagram showing similarities in the composition and relative abundance of zooplankton taxa between five sampling sites. The diagram was computed using Ward's method of analysis using Euclidean distance measure (Boot N:1000).

exchange of water with its neighboring open seas in the Southeast Asian waters could have brought large water mass advection or horizontal transport of water movements by ocean current, viz. Kuroshio. It is probable that the mesozooplankton may be carried by the Kuroshio Current during its course along the northwest Pacific Ocean. Several studies had shown that the western boundary currents off the east coast of the Philippines are of critical importance to the general circulation of the Pacific Ocean. The North Equatorial Current (NEC) in the Pacific Ocean (Figure 1) runs into the Philippine coast and bifurcates into the northward flowing Kuroshio and the southward flowing Mindanao Current (MC). The Kuroshio current flows northward along the east coast of the Philippines where it passes Luzon Strait before continually heading towards the east coast of Taiwan (Farris & Wimbush 1996; Qiu & Likas 1996; Hu & Cui 1989). The upper waters (0-600m) of the western boundary current continue to flow northward into the Okinawa Trough through the Yonaguni Depression and pass along the outer edge of the continental shelf of the East China Sea (ECS), forming the main track of the Kuroshio Current (Ujiie et al 2003 c.f. Hsiao et al 2011). Considering the flow of Kuroshio, it is suggested that the current originating from the northern Pacific equatorial waters carried with it a mixture of warm-temperate or subtropical zooplankton and inshore-offshore-oceanic species which were introduced into the waters of the northern side of the Philippines, where San Ildefonso Cape is located. Grice (1962), who investigated the calanoid copepods in northern Pacific equatorial waters where the Kuroshio Current originates, reported 58% of the copepod species which were also identified in the present study. From the Philippines, the Kuroshio Current traverses towards Taiwan, China and Japan bringing with it more mixture of warm-water species of zooplankton assemblage. The intrusion of Kuroshio Current through the waters of northern Philippines into Taiwan, China and Japan may also in part explain why most of the mesozooplankton community, particularly copepods, observed in the present study were similar to those copepod species that were reported as indicators of subtropical or warm-water in the above-mentioned adjacent bodies of water. It should be noted as well that some cold-water species, viz. *Calanus sinicus*, are not observed in the study area. Hwang et al (2006) showed *C. sinicus* with higher index values for winter which originates from the East China Sea (Hwang & Wong 2005). The absence of this species in the present study sites may further suggest the major influence of the Kuroshio Current intrusion with higher water temperatures as reported by Hwang & Wong (2005).

In order to determine the specific physical and chemical parameters of the water that may influence the relative abundance and diversity of mesozooplankton, Canonical Correspondence Analysis was used. The plots of the sites or stations along the first two canonical axes are shown for samples collected during (a) high tide and (b) low tide (Figures 6 a-b). The plot includes a vector plot that could be used to pinpoint important variables that can explain the differences in composition and abundance of zooplankton community structures among the five sampling stations during high and low tides. Results showed the importance of dissolved oxygen in affecting the abundance of zooplankton in the study areas. For example, during high tide (Figure 6a), station 2, which registered the highest mean dissolved oxygen value of 6.48 mg $L^{-1}$, recorded the highest relative abundance of zooplankton (Figure 7a). At low tide, Figure 6b revealed that stations 1 and 2, which are found on the negative axis, had high dissolved oxygen values (station 1: 6.67 mg $L^{-1}$; station 2: 6.63 mg $L^{-1}$) and likewise recorded the highest relative abundance of mesozooplankton (Figure 7b). Conversely, although station 4 (Figure 6b) recorded the highest mean value of dissolved oxygen (6.68 mg $L^{-1}$) at low tide, the mesozooplankton community was low in relative abundance (19.84%) when compared to those in stations 1 and 2. Generally, looking at the levels of dissolved oxygen content in the five sampling stations at high tide and low tide, the values were still greater than 5.0 mg $L^{-1}$, suggesting that such conditions are favorable for zooplankton community to thrive and be fairly abundant. Uy et al (2006) reported extremely high zooplankton density and abundance (specifically copepods) at dissolved oxygen above 5.0 mg $L^{-1}$. In fact, Roman et al (1993) observed that adult copepods die at oxygen concentrations <1-2 ppm and therefore avoid deoxygenated depths (Harada et al 1985) such that less developed deoxygenation in the water mass provide copepods with wider habitat space (Uye et al 2006) which could be the case in the present area. Hence, the results reflected in Figures 6 a-b is an indicative of the influence of dissolved oxygen on the abundance of mesozooplankton. Although, the present data suggests the influence of dissolved oxygen to the high diversity and abundance of mesozooplankton community structure in San Ildefonso Cape, Casiguran, Aurora, during high and low tides, other factors like transport of water masses by currents (Gomez et al 2000; Lopes et al 1999; Gowen et al 1998), characteristics of water masses (Tseng et al 2011), seasonal monsoon effects (Yoshida et al 2006), diverse feeding habits (Turner 2004), vertical migration (Lo et al 2004), sampling time (Hwang et al 2009) and mesh-size effects (Tseng et al 2011) may have played an important role in shaping the mesozooplankton community.

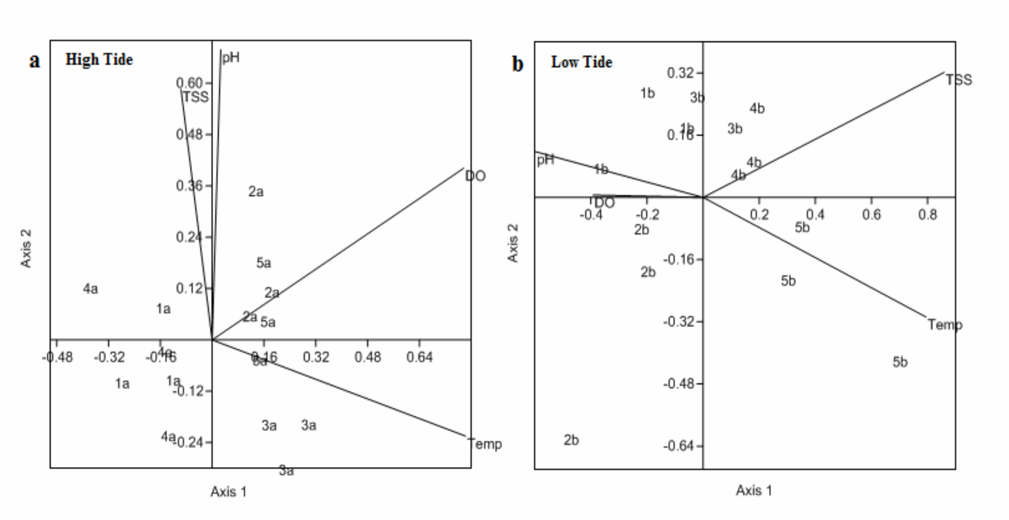


Figure 6. Results of the Canonical Correspondence Analysis- biplot showing the distance among the sampling stations during (a) high tide and (b) low tide and the physico-chemical factors that influence the abundance of zooplankton in San Ildefonso Cape, Casiguran, Aurora.

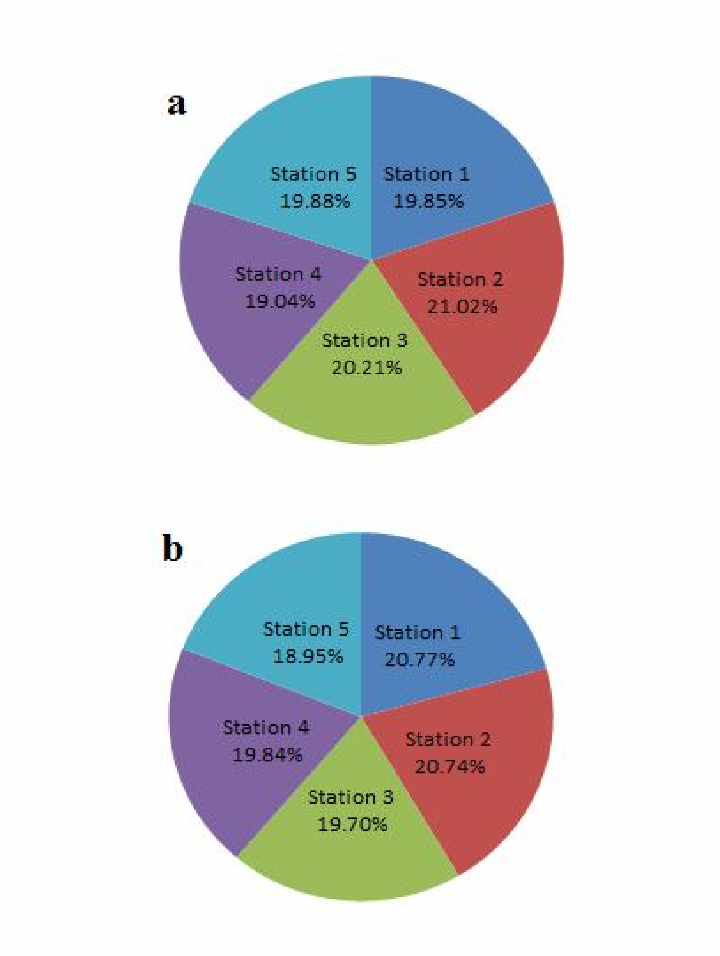


Figure 7. Relative abundance (%) of all zooplankton taxa in the five sampling stations during (a) high tide and (b) low tide in San Ildefonso Cape, Casiguran, Aurora.

**Conclusions**. The mesozooplankton assemblage, copepods in particular, in San Ildefonso Cape, Casiguran, Aurora, Philippines consisted of a mixture of highly diverse coastal, neritic, and oceanic warm-water to subtropical species. The highly diverse zooplankton community structure observed in San Ildefonso Cape can be used as a basis in saying that the area is considered as a stable marine ecosystem that host and cater diverse marine faunal and floral assemblages. Although, hydrological condition, viz, dissolved oxygen, may have influence the highly diverse zooplankton community, other factor such as the intrusion of the Kuroshio Current which had higher water temperatures could have played a vital role in shaping the mesozooplankton assemblage of the said area. Considering the importance of copepods as major component of the marine zooplankton and its function in marine food webs, the present records are therefore crucial in understanding the dynamics of marine ecosystems and are necessary for purposes of management and conservation of marine resources. It is recommended that the circulation patterns of the ocean current, particularly Kuroshio, must be included in any future biological and hydrological studies in order to describe in greater detail its influence in shaping mesozooplankton community structure in San Ildefonso Cape, Casiguran, Aurora.

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