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Megistobenthic faunal diversity of the Antalya Gulf: Crustacea

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1. Introduction

1.1 The importance of macrobenthos in the Mediterranean Sea

The Mediterranean Sea is a semi-enclosed sea and occupies a huge depression, which reaches a depth of 5270 meters as its deepest point (depth average of 1480 m) and is a relatively small sea compared with other oceans. It is connected in its western part, to Atlantic ocean by the shallow strait of Gibraltar, and in the southeastern part is connected with Red Sea by the artificial Suez Canal, opened in 1869.

The general water circulation of Mediterranean sea is highly complex, from Strait of Gibraltar the less saline waters of the ocean enters through the surface waters, while dense saline waters flow beneath in deep in the opposite direction into the Atlantic Ocean (Millot, 1987). In the Mediterranean Sea the great rate of evaporation exceeds precipitation and river runoff (Malonette-Rizzolli et al, 1999) causing a high salinity of the waters, from about 38 to 39.5 psu by the stratification of the water column. Furthermore, there are many hydrological characteristics of the Mediterranean Sea, such as the high oxygen concentrations and a decreasing of nutrient concentrations from west to east, which affect the structure of the pelagic food web, causing strong oligotrophic conditions (Danovaro *et al.,* 1999).

For its environmental structure, the Mediterranean marine ecosystem is highly vulnerable to perturbations, and it is going to rapid changes mainly due to the intense anthropogenic activity, that involve climatic changes, pollution, an over-exploitation of marine living resources with fishery, the establishment of alien species.

The impact of these pressures is leading to a degradation of Mediterranean ecosystem, so for this reason is necessary to have tools to study and monitoring the functioning of marine ecosystem to improve the identification of the main operative task to restore compromised equilibrium. The study how the biotic component responds to changes in the physical environment is an essential step to predict the consequences of these changes on the marine ecosystem. For this purpose, benthic organisms are superior to many other biological groups for their response to environmental stresses, providing fundamental data that are relevant to general objectives of most marine monitoring programs (El Komi and Emara, 2007).

Benthos or benthic organisms are referred as to all organisms that are living in or closely associated with the sea bottom (Stirn, 1981). The combination between river discharges and marine currents carries large amounts of suspended sediments to bottom regions, impacting the local ecosystems. Benthic communities play an important role in the marine ecosystems, being food for fish and cycling nutrients between the sediment and the water column. The amount of production and the part that is passed on the demersal fish via benthic organisms can be estimated qualitatively and quantitatively (Arntz, 1978).

The benthos is divided according to size in three classes:

- Macrobenthos: mainly organisms that are retained by sieves of 0.5 mm. This class can be further subdivided into megistobenthos (>25 mm), megabenthos (2-25 mm) and mixobenthos (0.5-2mm) (Bacescu et al,1971).
- Meiobenthos: organisms with size between 0.5 mm and 63 μm
- Microbenthos: organisms with size less than 63 μm

Benthic macrofaunal assemblages are important in the marine ecosystems that display a great variation in species composition of polychaetes, molluscs, echinoderms, and crustaceans living in burrows in the sediment (infauna) or on the sediment surface (epifauna). These assemblages represent the basic level of trophic chains, being food source for many species of commercial fish and shellfish. The variability of benthic assemblages on a site can reflect, in an integrative mode, the entire functioning of the marine ecosystem, representing a sum up of effects, which environmental factors have on each individual during a longer period and minimizing the adverse impact particularly on the marine ecosystem (El Komi and Emara, 2007). Macrobenthic communities have long been considered as a possible indicators for monitoring any anthropogenic impact or natural long term alterations in marine ecosystems, providing valuable information that cannot otherwise be obtained from other biological groups, because they adapt responding to environmental stresses (Bilyard, 1987; Kroncke, 2003).

A huge variety of environmental sources affect the biodiversity pattern of benthic organisms, in different ways. Substrate types, such as hard and soft bottoms and vegetative marine beds, play an important role on species richness and diversity pattern of benthos (Beaman and Harris, 2007; Kostylev *et al*, 2001). Other factors can structure the spatial benthic assemblages, such as the levels of dissolved nutrients (Cinar *et al*, 2012), the oxygen

content in the near bottom waters (Seitz *et al*, 2009) and total organic carbon content of the sediment and bottom depth (Mutlu and Ergev, 2013).

Macrofauna includes many phyla of invertebrates, but is generally considered that the most important taxa are molluscs, crustaceans and polychaetes (McLachlan, 1983). Benthic crustaceans are an important source of foods consumed by human, and have a relevant importance in nutrition of other marine organisms. They have been considered to be the most sensitive communities to changes in environmental variables, so they are good biological indicators for monitoring the ecological status of marine ecosystem and water quality (Gesteira & Dauvin, 2000; Kramer *et al*. 2013; Sanchez-Moyano & Garcia-Gomez, 1998).

1.2 The Levantine Sea: environmental and ecological features

The study area is located in the Antalya Gulf, Levantine sea (Figure 1). The Levantine basin is the second large and easternmost basin of the Mediterranean Sea. It is surrounded by the coast of Libya, Egypt, Israel, Lebanon, Syria, Turkey, and Cyprus, and the whole area is constantly subjected to anthropogenic inputs, particularly in the fishing grounds. The ecosystem of Levantine Sea has been affected by significant changes of fauna and flora due to biological invasion of Lessepsian species (i.e. marine species of Indo-Pacific origin passing through Suez Canal; Por, 1978).

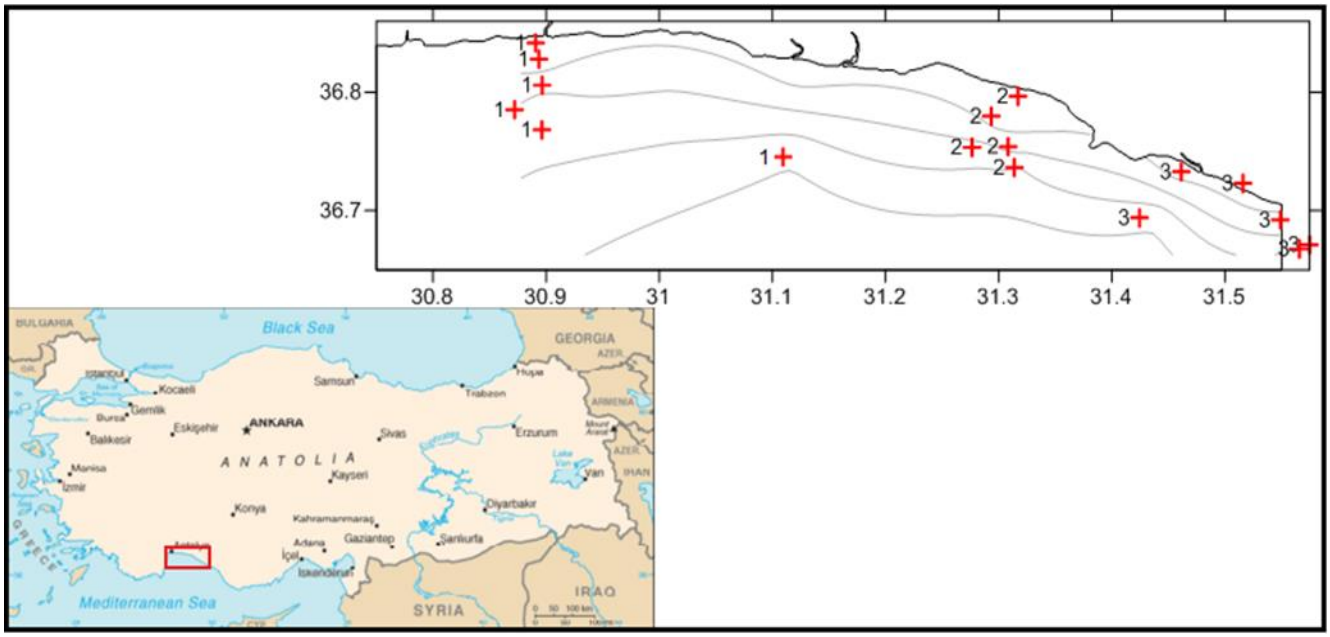

Figure 1 Location of study area

The continental shelf of the Levantine basin is generally very narrow with the exception in Mersin and İskenderun Bays, and in the region of Antalya there is one of the major troughs (with water depth of 1500 meters) of the northern Levantine basin (Ozsoy *et al*., 1993). The different features of hydrography and climatology in the Levantine basin allow four distinct water masses in the water column profiles: i) the Levantine Surface Water, that is warmest (16-25 ºC) and saltiest (38.8-39.4 psu); ii) the second is the Modified Atlantic Water, which originates from the Atlantic Ocean and it can be identified from salinity minimum (38.5-39 psu and about 17 ºC); iii) the Levantine Intermediate Water (LIW), the saltiest water mass of eastern Mediterranean that occupies the intermediate layers between 200 and 700 meters depth (39.1 psu and 15.5ºC); iv) the Levantine Deep Water, which is the colder and less saline than the LIW, with 38.7 psu and 13.6 ºC (Ozsoy *et al.,* 1989 and 1993). The LIW is formed by the cooling of the surface saline waters during winter, which are transported westward at a depth between 300 m and 500 m towards the Strait of Sicily and then towards Gibraltar. The eastern Mediterranean deep waters drops into the deeper parts of the basins, and these sinking waters carry all the nutrients through the deeper layers. This is one of the reasons why Levantine Sea is one of the world's poorest basins in terms of nutrient sources (Ozsoy *et al*., 1993).

In any case, as underlined before, is well known that all the Mediterranean Sea is poor in nutrient, and that the nutrient amount decreases from western to eastern part of the Mediterranean. This is mainly due to a limited external input and to a more intensive leakage of polluted river waters into the western part. Therefore these waters are ultra-oligotrophic and fluctuations of nutrient concentration were observed throughout the year. It has to be noted that during spring these waters displayed a low nutrient load in the surface (Uysal and Koksalan, 2006). In addition, the eastern Mediterranean has low plankton biomass and production (Stergiou *et al*., 1997). The Eastern Mediterranean has some of the world's most optically clear waters and the Secchi disc transparency ranges from 20 to 38 m depth (Ediger and Yılmaz, 1996).

These environmental conditions of Levantine waters (i.e. the scarcity of nutrient concentration, the continuous entering of invasive species, and the particular physical conditions) can lead to additional pressure on natural resources, and these could be considered the factors that mainly affect the benthic community structure.

Most of the previous benthic studies conducted were concentrated in the western part of Mediterranean Sea (Tselepides *et al*., 2000). Furthermore, the number of species in the Mediterranean has been changed with the increasing number of the Lessepsian invaders especially in the Levantine area. In the last two decades, many studies carried out in the Levantine area have been focused on the native and non-native species diversity of the benthic crustaceans, with new records of alien species and of crustaceans hugely reported in the Turkish waters (Cinar *et al*, 2006; Yokes and Galil 2006 ; Ozcan *et al*, 2006; Dogan *et al*, 2008). Until now, the number of marine alien arthropods in Levantine coast of Turkey is of 65 species, with a hot spot in the Iskenderun Bay, due its proximity to the Suez Canal (Bakir *et al*, 2014).

Nevertheless, also many studies were interested on distribution and ecological status of macrobenthic organisms in Turkish Levantine waters. For instance, Bingel *et al.* (1995) reported a total of 141 benthic species in Manavgat (the same area of the present study) with dominant taxa Annelida (67) and Mollusca. Gücü et al. (2001) identified 84 species in the İskenderun Bay with Annelida and Mollusca as dominant groups. An exhaustive study on benthic communities (infaunal and epifaunal communities) in the Mersin bay was conducted by Ergev (2002), in which 122 epibenthic species were reported with Annelida as the dominant group. Furthermore, Uysal *et al*. (2008) studied the distribution of benthic

communities in Cilician Shelf (northeastern part of Levantine) and identified 692 species of macrobenthos and the Annelida as dominant group. According to results of various studies on the benthos in the eastern part of Mediterranean Sea (Çınar *et al.,* 1998; Tselepides *et al*., 2000; Gücü *et al*., 2001; Ergev, 2002; Uysal *et al*., 2008; Mutlu and Ergev, 2007) Annelida was the main dominant group in the benthic communities and it was generally followed by Mollusca or Crustacea.

Since each dominant taxa of benthos showed different response to a variety of environmental parameters, some studies have recently concerned the spatio-temporal distribution of benthic assemblages and their relationships with environmental factors were assessed in many areas of Levantine basin (Mutlu and Ergev, 2012; Mutlu and Ergev, 2013; Mutlu, 2015). In the Gulf of Antalya, some ecological distribution studies were done (Ergen and Cinar, 1997; Cormaci and Furnari, 2002) but there have been no significant studies until now on spatial and temporal distribution of benthic crustaceans that related their community to ecological factors in this area.

Many alien benthic crustaceans are well established in the Levantine Sea replacing or filling the gap of ecological niches responded by the native benthic crustacean species (Mutlu, 2015). Moreover these invaders species play a conspicuous role in the host ecosystems, threatening native species, and they could affect the crustacean trawl fishery of the Levantine Sea with negative economic consequences (Boudouresque and Verlaque, 2005). Crustaceans, such as lobsters, crabs, and penaeid shrimps are very important for fishery due to high demand in the markets. In Europe, approximately 22 crustacean species are fished commercially. The crustacean trawl fishery in the Levantine area is very common and has an important role due to its quantity and the economic value of its landings. For its economic value, the crustacean fishery, particularly of penaeid shrimps, has been carried out using a specially designed bottom trawl that is called “shrimp trawl” in the easternmost part of Levantine Sea (Can *et al*., 2004).

However, all the Levantine coasts of Turkey are strongly subjected to crustacean fishery with the traditional trawl net, especially to catch high-value decapods. Ten shrimp species have been reported to be commercially important for Turkish trawl fisheries in the Levantine Sea: *Penaeus semisulcatus, Melicertus kerathurus, Marsupenaeus japonicus, Parapenaeus longirostris, Metapenaeus monoceros, M. stebbingi, Trachypenaeus curvirostris, Melicertus hathor, Aristaeomorpha foliacea, Plesionika heterocarpus* (Bayhan *et al.,* 2003).

1.3 *Parapenaeus longirostris*

The common name of *Parapenaeus longirostris* (Lucas,1846) is deep-water rose shrimp, for its distribution and its coloration. This shrimp shows a wide bathymetric distribution, occurring from 20 to 750 m depth and being more abundant in bathyal zone between 100 and 400 m depth on sandy and sandy-mud bottoms (Sobrino, 1998; Tom *et al*., 1988). However, biomass is higher between 200 and 400 m depth, showing a marked, size-dependent distribution with depth, with small individuals being found at the edge of the continental shelf (Abelló *et al*., 2002). This demersal species has a wide distribution, being present in the entire Mediterranean as well in the eastern Atlantic from Portugal to Namibia (Pérez-Farfante & Kensley, 1997). The species plays an important ecological role in many demersal communities of the continental shelf and upper part of the continental slope (Sobrino *et al*, 2005) .

Like all penaeids, the body of the deep-water rose shrimp is laterally compressed and the part of cephalothorax is protected from a carapace. Its color is pink - orange, darker in the carapace and in the rostrum. In females the coloration of gonads fluctuates from white to greenish, depending on the sexual maturity stage. there is a distinctive The epigastric tooth of the cephalothorax and the straight or slightly curved carapace rostrum with 7 dorsal teeth and without teeth in the ventral part are distinctive features distinguishing the deep water rose shrimp from other penaeids (Falciai and Minervini, 1992). The surface of the shrimp cuticle is smooth and free of bristles. On the lateral part of carapace a longitudinal sutures extending from postorbital margin to almost posterior margin. An antennal spine, an hepatic spine and an branchiostegal spine are present in the lateral part of carapace. The telson is armed with three teeth fixed. Petasma is symmetrical and semiclosed and thelycum is closed (Sobrino *et al*, 2005).

The deep water rose shrimp is one of the most important commercial decapoda species in bottom trawl fisheries throughout its distribution range, in Atlantic and Mediterranean waters, where it is caught as target or by-catch (Ribeiro-Cascalho and Arrobas, 1987). Regarding the crustaceans with commercial value in the Mediterranean Sea, this shrimp is the fifth in order of importance considering the total biomass landed (Stamatopoulos, 1993). In Turkish waters, total reported catches of *Parapenaeus longirostris* were 2501.8 tons in 2014 and 93.9 tons of these were from the Levantine Sea (TUIK, 2015).

Because of its great commercial importance, many studies were carried out in the last decades regarding *Parapenaeus longirostris*, which have permitted to have an assortment of detailed information on its biology, distribution, abundance, fishery and stock assessment (Abelló *et al*., 2002; Bayhan *et al*., 2005; D'Onghia *et al*., 1998; Guijarro *et al*, 2009; Sobrino, 1988 , etc).

Figure 2 deep water rose shrimp *Parapanaeus longirostris*.

1.4 Objectives

This thesis deals with to analyze the spatial and temporal distribution of the megistobenthic crustacean assemblages of Antalya Gulf. In order to provide a comprehensive overview of the spatio - temporal patterns of crustacean community, I have also investigated the correlation of biological data of assemblages with a set of environmental parameters, including physical, chemical and bottom features of the study area.

Furthermore, for its economic importance in Levantine waters, a focus analysis was done to obtain information of morphometric characteristic and study the length frequency composition of the *Parapenaeus longirostris* population of the Antalya Gulf where it is an important target species of fishery.

2. Materials and Methods

2.1 Study area and sampling

The study was conducted on the Turkish continental shelf off the Antalya Gulf, within infra-littoral and circa-littoral zones. The Gulf of Antalya is subjected to high intensity human uses linked to coastal zone pressures such as tourism and maritime traffic, especially during summer. In the study area there are the Manavgat river and two little streams, which represent the major sources of freshwater in the Antalya Gulf. Throughout the year, in the area of Antalya, fishing is not allowed within 2 miles of the coast. The sampling stations were located in two different areas. The first area is open to fishing and covers the region of the towns of Lara and Side. The second area is a closed fishing area and includes the region between the cities of Side and Gazipasa. In this area any kind of trawling is forbidden according to the Turkish law (RG 26.02.2005 / 25739).

The data analyzed in the present work derived from experimental trawl surveys within a framework of the project no: 2014.01.0111.001 supported by Scientific Research Project Coordination Unit of Akdeniz University. Samples were collected by the R/V “Akdeniz Su” (fig 3) (total length 26.5m, 670 kW of engine power) of the Faculty of Fisheries, Akdeniz University. The data were collected in May, August and October 2014, and February 2015, thus representing the seasons of the year.

Figure 3 Research vessel “Akdeniz Sü”

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Samples were collected on three oceanographic transects. called T1, T2 and T3. T1 and T2 were situated in the area open to fishery, while T3 in the no-fishing area. Each transect consisted of five different depths: 10, 25, 75, 125, and 200 m depth. Furthermore, during each cruise additional hauls were carried out at 300 m depth in T1 and T3, and for each cruise intermediate stations between the transects in order to provide a better ecological and environmental characterization of the area. In figure 4 and table 1 are shown the sampling sites in the study area, and the coordinates of sampling stations with corresponding code (i.e. for T1 station at 10 m depth of August cruise the code is AT1_10) .

The duration of each haul (bottom time) was about 30 minutes and position was recorded with Global Positioning System (latitude and longitude) in 5 second intervals from the start to the end of trawling.

The sampling device was a polyethylene otter trawl net with a float line length of 15.3 m. The cod end had a square mesh opening of 44 mm, as usual commercial net. This cod end was protected by a polyamide cover net with 25 mm mesh size.

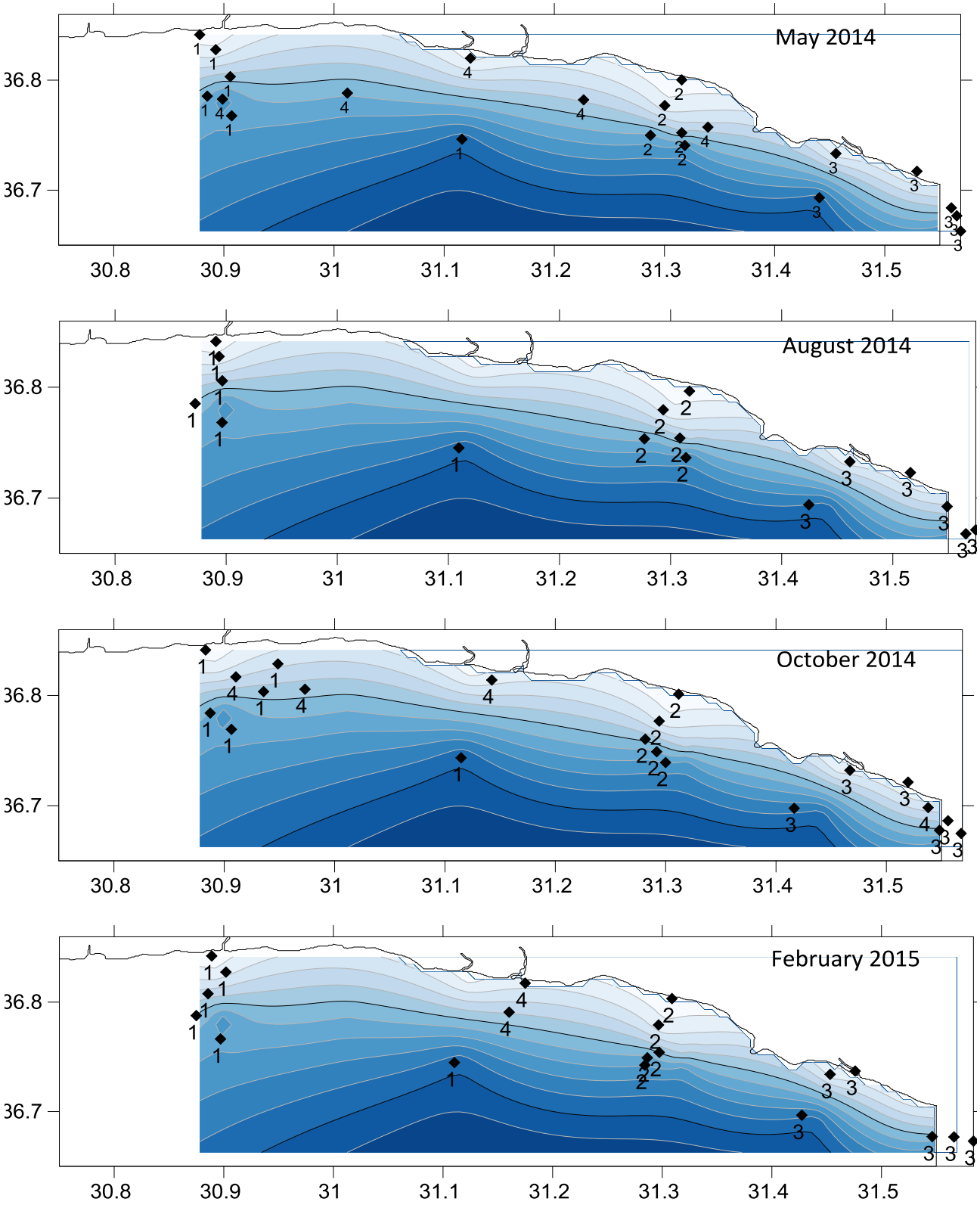


Figure 4 Sampling stations in each season in the Antalya Gulf.

1: T1, 2: T2, 3: T3. 4 denotes intermediate stations for each season.

Table 1 Coordinates of sampling stations for each season in Antalya Gulf

Table 1: Coordinates of sampling stations for each season

11 - 16 May 2014			20 - 27 August 2014			20 - 27 October 2014			9 - 15 February 2015		
Station	Latitude (°N)	Longitude (°E)	Station	Latitude (°N)	Longitude (°E)	Station	Latitude (°N)	Longitude (°E)	Station	Latitude (°N)	Longitude (°E)
T1_10	36.84132346	30.87810003	T1_10	36.84134128	30.89080233	T1_10	36.84126338	30.88309696	T1_10	36.84218387	30.88902555
T1_25	36.82774395	30.89263578	T1_25	36.82772923	30.89366988	T1_25	36.82865718	30.94865819	T1_25	36.82742756	30.90198699
T1_75	36.80319503	30.90583659	T1_75	36.80576886	30.89654418	T1_75	36.803538	30.9356365	T1_75	36.80769858	30.8856577
T1_125	36.78548032	30.88496547	T1_125	36.78517359	30.87214243	T1_125	36.7840598	30.88729767	T1_125	36.78767659	30.8749118
T1_200	36.76759552	30.90711534	T1_200	36.7681558	30.89636239	T1_200	36.76925342	30.90650008	T1_200	36.76633427	30.89705847
T1_300	36.74634714	31.1161618	T1_300	36.74525836	31.10942595	T1_300	36.74343597	31.11463756	T1_300	36.74476548	31.11040775
T2_10	36.80024172	31.31565849	T2_10	36.79648051	31.31701514	T2_10	36.80118476	31.31175956	T2_10	36.8032112	31.30887111
T2_25	36.77694624	31.30023919	T2_25	36.77959733	31.29338607	T2_25	36.77674453	31.2942088	T2_25	36.77915639	31.29666387
T2_75	36.75219684	31.31571844	T2_75	36.7540649	31.30838288	T2_75	36.76034173	31.28150357	T2_75	36.75407925	31.29729603
T2_125	36.74985681	31.28732168	T2_125	36.75339863	31.27643667	T2_125	36.7489692	31.29190712	T2_125	36.74909902	31.28638764
T2_200	36.74069155	31.3184769	T2_200	36.73640677	31.31384552	T2_200	36.73917121	31.29999643	T2_200	36.74241693	31.2841643
T3_10	36.71720096	31.52922601	T3_10	36.72293577	31.51589391	T3_10	36.72139819	31.5196816	T3_10	36.73704434	31.47599963
T3_25	36.73330747	31.45568797	T3_25	36.73272503	31.46141624	T3_25	36.73211202	31.4669974	T3_25	36.73400216	31.45320566
T3_75	36.6839285	31.56045333	T3_75	36.69229982	31.54890623	T3_75	36.68634902	31.55585651	T3_75	36.67301977	31.58389583
T3_125	36.67671468	31.5653915	T3_125	36.67122208	31.57467216	T3_125	36.67484515	31.56778735	T3_125	36.67682575	31.56614242
T3_200	36.66272584	31.56892016	T3_200	36.66767454	31.56574693	T3_200	36.67771066	31.54814649	T3_200	36.67711553	31.54632717
T3_300	36.69309615	31.44063797	T3_300	36.69388778	31.42444204	T3_300	36.6977013	31.41645549	T3_300	36.69667904	31.42737321
T4_65	36.75729249	31.33946727				T3_50	36.6982905	31.53788469	I_10	36.81732154	31.17499523
I2_30-60	36.78211781	31.22659897				A_50	36.81689158	30.91054856	I_40	36.79079024	31.16035574
I3_15	36.81997182	31.12387173				A_100	36.80570953	30.97319178			
I4	36.78826288	31.0121733				A2_15	36.81404107	31.14249882			
I5_100	36.78278611	30.89880001									

2.2 Onboard work

2.2.1 Collection of benthic communities

The organisms were caught with cod-end and cover net, and the operations described below were carried out for both types of device. For each haul, a preliminary sorting was carried out to separate megafauna (crustaceans, sponges, and molluscs) from fishes and no-living inorganic and organic materials such as litters (Fig. 5). Afterward, the sorted megafaunal organisms were stored in plastic jars and were fixed with 5% formalin-seawater solution buffered with borax (40 g for each liter of formalin-seawater) for laboratory analysis. Very abundant species were subsampled randomly by weight to provide a representative sample of the species.

Figure 5 Sorting of megistobenthic fauna onboard.

2.2.2 Environmental parameters

The environmental parameters considered in this study were chemical, physical, biological and sedimentary parameters (measured at surface and near bottom water, see table 2). All the parameters have been generally collected just before the sampling or at the end of the trawl operations picking up a sample of seawater using a polyethylene Nansen bottle (fig. 6). The transparency of water was measured by a Secchi disk, a 30 cm-diameter plain black-white circular disk that is lowered by hand into the water column until to the depth at which it is no longer visible. The length at which the disk vanishes is called the Secchi depth, and is taken as measure of transparency.

Table 2 List of environmental parameters as physical, chemical, biological and sedimentary (Superficial sediment) parameters measured at the sampling stations and abbreviations of the parameters used in the analyses.

Physical and chemical parameters	**Biological parameters**	**Sedimentary parameters classified with VBT**
Secchi disk depth (m)	Seston - 1 mm (g); Se1	
Temperature (ºC); SST and NBT	Seston - 0,5 mm (g); S2	1; Rocks covered with *Posidonia*
Salinity (PSU); SSS and NBS	Seston - 0,063 mm (g); S3	2; Muddy sand
Oxygen (mg/L); SSOx and NBOx	Bioseston - 1 mm (g); Bi1	3; Sand
pH; SSpH and NBpH	Bioseston - 0,5 mm (g); Bi2	4; Mud
Density, sigma-t; SSD and NBD	Bioseston - 0,063 mm (g); Bi3	5;Sandy mud
Conductivity (S/m); SSC, and NBC	Tripton - 1mm (g); Tr1	
Chl-α (mg/mL); SSChl and NBChl	Tripton - 0,5mm (g); Tr2	
Total suspended matter (mg/mL); STSM and NBTSM	Tripton - 0,063mm (g); Tr3	

The salinity, dissolved oxygen, temperature, pH and conductivity were measured with a YSI multi-parametric probe. The density of the seawater (ρ) was calculated using the equation from Fofonoff & Millard (1983). The same seawater sample was used to analyze the total suspended material and chlorophyll-α. To determine the suspended material, one liter of seawater was filtered onto a microfiber filter with a retention of 1.2 µm using a vacuum pump with a filtered funnel and a graduated cylinder.

For the chlorophyll analysis, one liter of seawater was filtered onto a filters of 0.7 mm pore size and 47 mm of diameter using a vacuum of less than 0.5 atm. The filters were stored in the freezer (< 0°C) until the laboratory analysis.

Furthermore, seawater samples were collected by a Nansen Closing net to analyze the zooplankton of each haul. At the end of the haul, the outer side of the net was scattered down with surface seawater to concentrate the organisms in the collecting container. The samples were size-fractionated through a series of sieves of 1, 0.5 and 0.063 mm mesh size, and each size was filtered onto a glass fiber filters through vacuum pump. Lastly the samples were frozen for treating in the laboratory.

Figure 6 Nansen Bottle to sample seawater.

2.3 Laboratory work

2.3.1 Environmental parameters

Each filter of total suspended material, after defrosting at room temperature, was dried in an oven at 60°C for 24h. The dry weight of filters was measured on an analytical balance (Radawak A220) . The final amount of suspended material was obtained by subtracting to the dry weight of suspended material the weight of the empty filter after drying.

The Chlorophyll-α amount (Chlα, mg/mL) was assessed with an acetone-extraction method. Filters were homogenized with 10mL of acetone solution (90%) and maintained in the dark and cold. After 24h, samples were gently centrifuged and absorbance was measured at different wavelength (665, 645 and 630 nm) at the spectrophotometer. The filtered samples were blanched with a solution of 90% of acetone at 750 nm wavelength. The [Chlα] was calculated with the following equation:

$$Chl\alpha = [11.85\,(A665 - A750) - 1.54\,(A645 - A750) - 0.08\,(A630 - A750)] * Va * l^{-}1 * V^{7}$$

where

Va is the acetone volume (expressed in mL) and *l* path length of cuvette (cm) and V^{7} is filtered seawater sample volume (mL) (Lorenzen, 1967).

The zooplankton analysis was carried out as following: after defrosting at room temperature, each filter was dried in an oven at temperature of 60ºC for 24h and weighted on an analytical balance to determine the dry weight. Then each filter was reduce to ashes in a muffle furnace at 500ºC for 6 hours, and weighted again. Furthermore, three aliquots of filtered seawaters were treated in the same way described above to determine the blanks. The mean dry weight of blanks was subtracted from the measured dry weight of sample seawater to determine the total organic and non-living matter (Seston). The ash weight, which represents the inorganic fraction (Tripton), was subtracted from the dry weight for determination of the organic fraction (Bioseston).

The information on bottom types is encoded in the echo-signal of the echo-sounder and acquired simultaneously with GPS data. During surveys different echoes can be observed on the oscilloscope: hard bottoms produced a sharp echo-signal type of high amplitude while soft bottoms produced an elongated echo-signal type of low amplitude. In order to classify

the different bottom types the Fractal Dimension method implemented in Bio Sonics Bottom Classifier VBT was used in this study. In this software, the Fractal Dimension (FD) is a measure of the irregularity of an echo envelope obtained from the bottom. By classifying the echo-signal envelope in terms of its FD, the shape of the envelope can be defined by associating it with a FD number. Since the echo envelopes associated with different bottom types show regularities in shape, bottom echoes can be classified as function of FD.

2.3.2 Sorting and identification

The benthic crustaceans were sorted out from megafauna jars and transferred in a 70% ethanol-water solution, keeping cod-end and cover organisms separated. After sorting, crustacean specimens were identified and recognized to species level or to the lowest possible taxonomic level. Olympos binocular Stereomicroscope was used to examine the details of appendages of tiny species. Keystone and common species for each station were identified.

Taxonomic identification of species were based principally on “Mediterranee et mer Noire Volume I” (Fischer, 1973) and the checklist WoRMS (World Register of Marine Species, http://www.marinespecies.org). For a better identification of Lessepsian species it was consulted the website of CIESM (Atlas of Exotic Species in the Mediterranean).

2.3.3 Biomass and Abundance

After identification, the abundance and the wet-weight (biomass) of each species were calculated. To determine the weight, all specimens were put on a paper for a while and then weighted by using a digital balance to the nearest precision of 0.001 g.

To study the length-weight relationship of commercial species, individual size was measured with a digital caliper to the nearest precision of mm.

Different biometrical measurements were taken for each taxonomical group, in relation to the morphology of species. The analyzed species were *Marsupenaeus japonicus, Penaeus hathor, Penaeus semisulcatus, Melicertus kerathurus* and *Parapenaeus longirostris, Maja squinado*, and *Squilla mantis*. Here in the thesis, how just said, I focused only on deep-water rose shrimp *Parapenaeus longirostris*.

For each specimen of *Parapenaeus longirostris* the following biometrical measurements were taken:

- Carapace length (CL) from the inside of the eye socket to the posterior margin of cephalothorax (Holden and Raitt, 1974).
- Carapace width (CW) the maximum width of cephalothorax
- Total length (TL) from the tip of the eye socket to margin of the telson.

The sex was determined observing the presence of petasma in males, or the thelycum in females. Individual whose sex determination wasn't possible because decomposed or deformed were classified as not identified.

2.4 Statistical analysis

2.4.1 Environmental parameters

All environmental data of four seasonal cruises were organized in a matrix (in the first column the list of environmental parameters and in the first row the stations), and were normalized to allow comparison between different unit of measurement.

Based on these normalized physical variables, Principal Components Analysis (PCA) was applied to create an ordination that highlight the explanatory environmental variables and components of spatio-temporal description of the study area. The technique consists in ordering the point-sample along the axes (one for each variables). The goodness of representation of the point-sample is evaluated by the variance of the first two axes. This analysis was based on dissimilarity matrix created on Euclidean distance coefficient and was performed by PRIMER-E v6 (Clarke and Gorley,2006).

The formula of Euclidean distance index is:

$$d_{jk} = \sqrt{\sum_{i=1}^{p}(y_{ij} - y_{ik})^2}$$

Where j,k are the countable indices of samples, and i=1…p are variables used in the analysis.

The software SURFER was used to plot the graphs of explanatory environmental parameters (density, temperature, dissolved oxygen and salinity) for each season to show main differences among depths.

2.4.2 Crustacean community analysis

The biomass (g) and abundance (N) data collected in the laboratory for each species, were organized into two arrays. Each matrix showed in the first column the list of species and in the first row the stations. In the same files was added the value of subsample measured onboard for each haul. For each station abundance (N/Km²) and biomass (g/Km²) data were standardized using the trawling area. The trawling area was calculated over the coordinates obtained by the GPS and using the head rope length (35 m) (Sparre, 1998). Sampling dates and coordinates of stations are shown in Table 1. At the end, biomass and abundance data of cod-end and cover net were sum up together for each station, and over these data all the analysis were performed.

At first a qualitative and quantitative description of the crustacean community of area was done (over biomass and abundance) based on the following three numerical indices:

1) Frequency of occurrence is expressed as the percentage of total frequency of occurrence of all species in the study area (Holden and Raitt, 1974).
2) Numerical occurrence is defined as the total individual percentage of each species among total individuals of all species in study area (Holden and Raitt, 1974).
3) Dominance (Soyer index) is similar to frequency of occurrence method, this is a qualitative distribution of occurrence percentage of each species among the stations. According to Soyer (1970), species with D>50% are considered constant species, those with D between 25% and 50% are common species while those with D values > 25% are considered rare.

For the preliminary analysis of the crustacean community the abundance and biomass data were estimated per square meter.

As an indication of crustacean faunal characters, a set of diversity indices was calculated. The number of species (S) the abundance of species (N), the biomass of species (B), Margalef's index (d), Pielou's evenness (J') and Shannon-Wiener diversity (H', log e base) indices were calculated for each seasons, transect and depth. These indices were calculated

with *diverse* function of PRIMER-E v6 The main aim of these faunal indices is to reduce the multivariate information of assemblage data in a single index, which can be easily handle by univariate analysis (Clarke and Warwick, 2001).

The formulas of these indices are the following:

- Abundance of individuals (N) is the number of individuals present in the sample
- Species richness (S) is given as the total number of species present in the sample.
- Margalef's index (d) is an index of species richness, which also incorporates the total number of individuals (N) and is a measure of the number of species present for a given number of individuals:

$$d = (S - 1)/logN$$

- Shannon-Wiener diversity (H', log e base) is the most commonly used diversity measure:

$$H' = -\sum pi \log(pi)$$

Where p_i is the proportion of the total count arising from the *i*th species.

- Pielou's evenness (J') is an expression of equitability in the sample, that is how evenly the individuals are distributed among the different species, and is expressed as:

$$J' = \frac{H'}{H'_{max}} = H'/\log S$$

Where H'_{max} is the maximum possible value of Shannon diversity (Clarke and Warwick, 2001).

Three-way ANOVA was tested for each diversity indices among seasons, transects and depths. This univariate analysis was done with software IBM SPSS Statistics 21.

Spatio-temporal changes in crustacean community composition were visualized from multivariate analysis based on triangular matrices of Bray-Curtis similarities using transformed data. The biomass and abundance data were transformed with method "Taylor's power law" with log(x+1) to weight the influence of common and rare species. The Bray-Curtis similarity index was used to create a similarity matrix between samples (stations) for both abundance and biomass transformed data.

This index was chosen because provides more reliable results in the study of benthic communities (Faith *et al*, 1987) . The formula of Bray-Curtis index is the following:

$$S_{jk} = 100 * \left(1 - \frac{\sum_i |x_{ij} - x_{ik}|}{\sum_i |x_{ij} + x_{ik}|}\right)$$

Where S_{jk} is the similarity distance between samples j and k, and xij is the value of individuals of species i in sample j and x_{ik} is the values of species i in sample k.

Based on similarity measures of the Bray-Curtis index, the *Hierarchical Cluster Analysis* was done, and results were displayed in a dendrogram. This is an agglomerative method employing group-average linking, used to examine assemblages grouping of each sample station. Ordination of the crustacean community was performed by n*MDS* (non metric multidimensional scaling) to evaluate the separation between groups resulting from the cluster analysis (Field et al,1982). This ordination creates a map (in two dimensions) of the relation of community composition of the sample stations, where two samples are near to each other if their species composition are similar, while are far if their species compositions are different.

Three-way PERMANOVA (permutation-based MANOVA) (Anderson, 2001) was tested for differences of the crustaceans community composition among the season, transect and depth, and between their interactions. Depth and transect are fixed factors, while season is a random factor. In case of P-value <0.05, the differences can be considered significant, and pair-wise test was used to evaluate which level gives a significance variation.

SIMPER analysis (*Similarity of Percentage)*, using the matrix on abundance data, was performed to indicate the percentage contributions of each species to the similarity within groups and dissimilarity between groups of samples. SIMPER analysis allows to identify the contributor species characterizing each group of samples and to determine the discriminator species between groups, comparing in turn, each sample in one group with each sample in the other group (Clarke and Warwick, 2001).

All statistical analyses described above (multivariate analyses, faunal indices), were performed throughout software PRIMER-E v6 & PERMANOVA+ (Clarke and Gorley, 2006).

2.4.3 Relation between biological data and environmental parameters

To evaluate the relation between crustacean community and environmental characteristics of the study area, all the parameters studied within the project were considered, including bottom type, total suspended material, zooplankton, and chlorophyll-α.

The BIO-ENV analysis (Clarke and Ainsworth, 1993) was applied to investigate a combination of environmental variables that provide best explanation of the benthic crustaceans community. In the BIO-ENV analysis the similarity matrix of the community is correlated with the similarity matrix of environmental parameters (based on Euclidean distance).

These matrices are converted in ranks matrices to be compared with a coefficient rank correlation, the Spearman coefficient (ρ). This is defined as a coupling coefficient between elements of the two similarity matrices. Values of ρ close to zero correspond to the absence of coupling between the two patterns. The highest value of all possible ρ calculates identifies the best combination of environmental variables that explains the biotic community.

To show the relationship of the crustacean assemblages with the environmental parameters, a canonical extension of principal component analysis, canonical correlation analysis (CCA) (Ter Braak and Smilauer, 2002) was applied to log(x+1) transformed crustacean biomass data (CANOCO for Windows 4.5).

2.4.4 Commercial species: **Parapenaeus longirostris**

The spatio-temporal distribution of *Parapenaeus longirostris* species over its biomass was shown throughout SURFER 12 software. A bubble plot overlaid on an nMDS ordination was applied to its abundance data to detect tendencies with depth. It was examined the contribution that this species gives to average dissimilarity between depth groups (including the 300meters) through SIMPER analysis.

The size structure (Length-Weight relationships) and characteristics of the population of *Parapenaeus longirostris* were investigated.

At first was made a sex ratio analysis. For this analysis all morphometric data of species were put together in a file, and the specimens sexually non-identified were excluded. The sex ratio is defined as the proportion between number of female and male individuals.

Chi-square test ($\chi 2$) was used for comparisons of number of sex with null hypothesis that the proportion of male and female was 1:1.

The length and weight data were transformed with logarithmic transformation (Log_{10}), to obtain a normal distribution.

Resulting transformed morphometric parameters were used for univariate analysis to test and to investigate the morphometric variation of *Parapenaeus longirostris* and its spatio-temporal distribution in the study area, but only most relevant results are shown in this thesis.

Three-way ANOVA was tested for each morphometric variable among seasons, zones (fishing zone and protected zone) and depths.

These univariate analyses were performed with software IBM SPSS Statistics 21.

Morphometric growth relationships (CL, CW and TL with Weight) were determined separately for both sexes. The carapace length-weight relationship (CL-W) were calculated using the exponential function: $W= aCL^b$ (Ricker,1975) where W is the total weight of specimens (g) and CL is the carapace length (mm), a is the intercept on Y axes and b is coefficient of allometry. The association degree between CL and W was calculated with the determination coefficient (R^2). This analysis was performed to determine the type of growth of species. The b value reveals if the animal has an isometric growth (b=3), or an allometric growth (negative allometry b<3 or positive allometry b>3 (García-Rodríguez, M., 2009).

In order to outline the population structure this shrimp, from the determination of age classes and their relative abundance, it was performed the analysis of length frequency distribution. This analysis was made by the Bhattacharya method (Gayanilo *et al.,* 2002), a model progression analysis, using FISAT II software (FAO-ICLARM *Fish Stock Assessment Tools*, VERSION 1.2.0). This is a packages for analysis of length-frequency data, but also enables related analysis of size at-age, catch-at-age, selection and other analysis.

At first morphometric data were analyzed on MS Excel with Costfunction to calculate Frequency/No. of bins and the smallest class of length used for Bhattacharya method.

With Bhattacharya method were identified the various peaks of each modal class, which correspond to individual cohorts, highlighting the age classes. The cohort is composed by all the animals born in the same period and comes from same spawning season (Bombace and Lucchetti, 2011). Each representative component, with a separation index greater than 2, was assumed to be a single cohort (D'Onghia *et al.,* 2005). A relevant parameter is the separation index (SI) that estimates the possible overlap between the different classes. After the differences of the resulting mean length of female and male were evaluated with pair sampled t-test between Female and Male, by using software IBM SPSS Statistics 21.

3. Results

The AT2_10 station was removed from the multivariate analysis of crustacean community because the sample of benthic organisms dd not include representative of this taxonomic group. The experimental design, at the beginning, was performed with all sampling stations, and later AT3_10, AT3_25 and OT1_10 stations were removed from analysis to optimize the results and reduce the high variability due to the lack of several crustacean species that have been found commonly in the other stations. The crustacean assemblages in these stations were completely different from the others, being present only *Trachysalambria curvirostris* (Stimpson, 1860) in August stations and only *Thalamita poissonii* (Audouin, 1826) in October station. The definitive experimental design of this thesis was performed removing 300 m depth stations to optimize the results and to show clearly the significant differences.

3.1 Characteristic of study area

Regarding sedimentary structure, a heterogeneous pattern of the substrate bottom types was detected among the bottom depths, and five types of substrate were distinguished in the study area. Bottom types of the shallowest stations (10 m depth) was largely constituted by rocks with a covering of *Posidonia oceanica*, 25 m depth stations by muddy-sands, 75 and 125 m depth stations were composed primarily by sands, 200 m depth by muds and the deepest stations of 300 m depth were characterized by sandy muds.

Overall, physical characteristics of the study area showed a regular pattern with a general upward or downward trend from inshore to offshore and both sea surface and near bottom waters were significantly different among seasons. Mainly distribution pattern in August displayed similarity with that of in October, and both were different from the other two months (February and May).

The variation of physical parameters was mainly explained by axe 1 of PCA with 41.7% (Fig 7). The PCA showed that this variation was resulted from a set of physical parameters such as SST and NBT and Secchi disk in increasing trend, and of SSD, NBD and SSOx in decreasing trend. The second principal component, PCA2, explained such a variation with 19.1% and resulted mainly from a decreasing trend of SSD, SSS, and Depth.

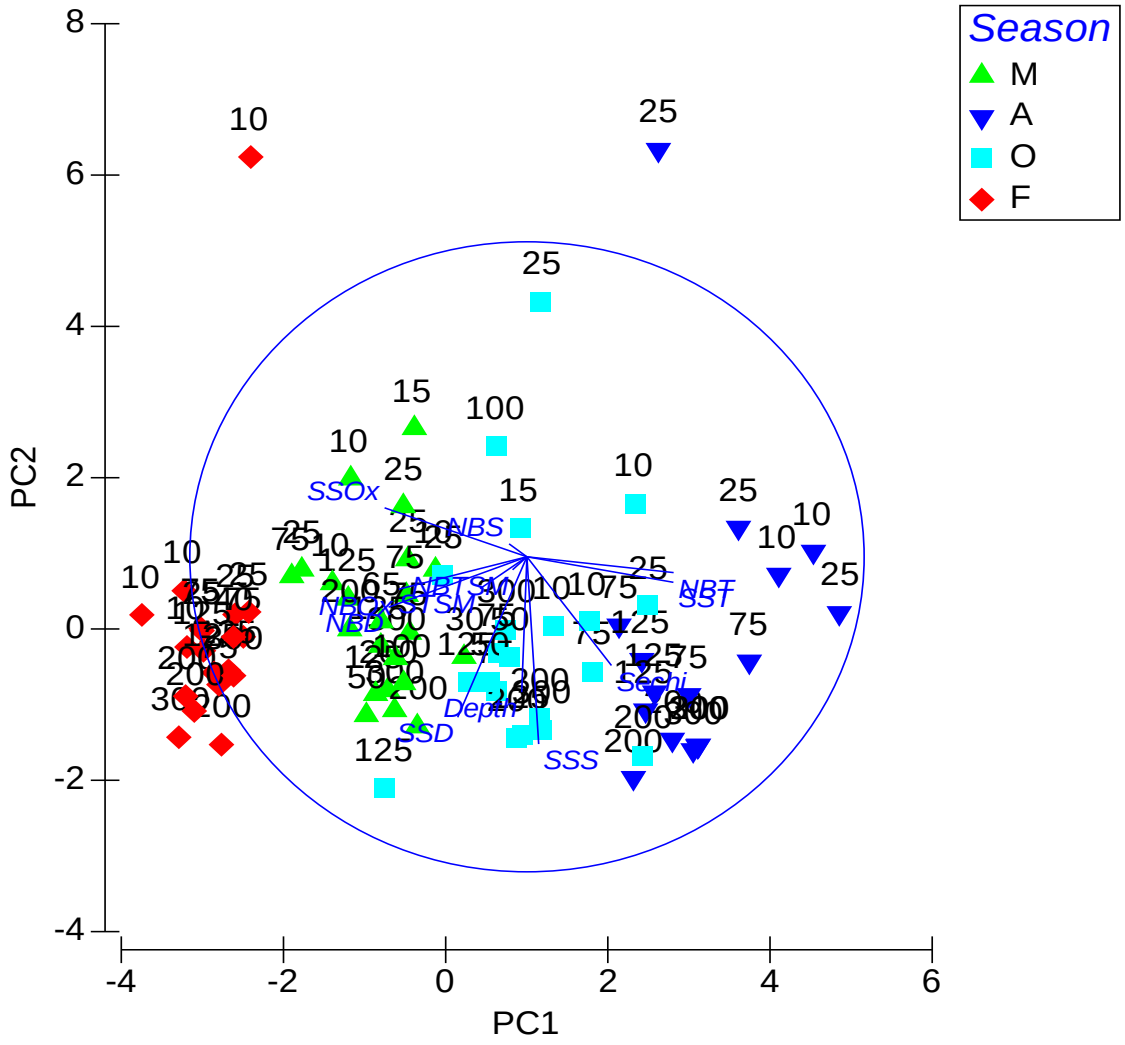


Figure 7 Principal Component analysis (PCA) of physical parameters of Antalya gulf.

A significant difference in SST and NBT was not observed among the transects (fig 8), with an exception of colder water in the station (T3_10) in front of Manavgat river, mostly in August and in February.

The February SST and NBT lightly increased from the shallow to deeper waters, passing from 19.7 to 20.5 °C and from 18.9 to 20.5°, respectively. On the contrary, these temperatures decreased from inshore to offshore in August, passing from 27.6 to 25.2°C (SST) and from 27.6 to 24.6°C (NBT). In May and in October the temperatures were no significantly different.

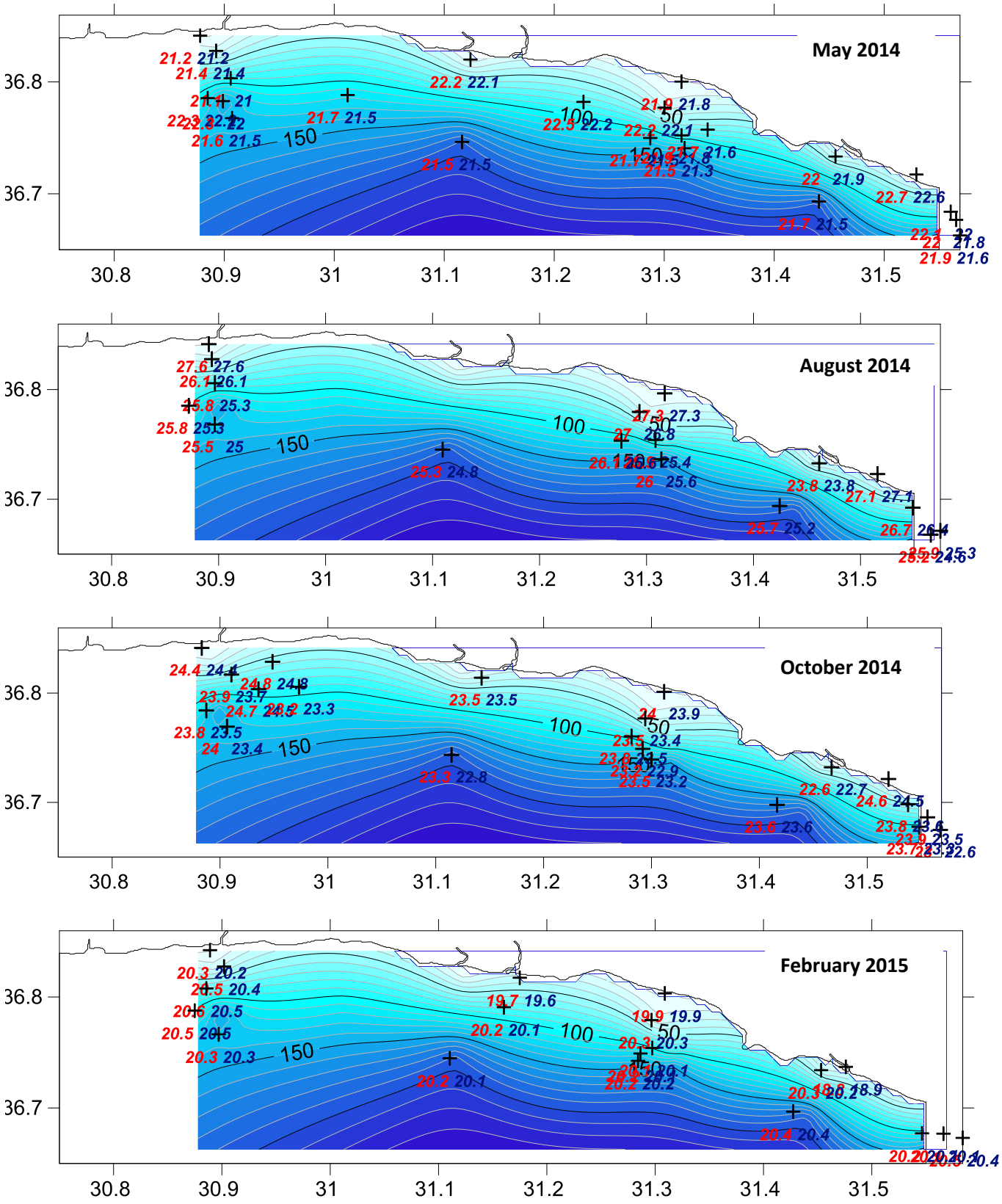
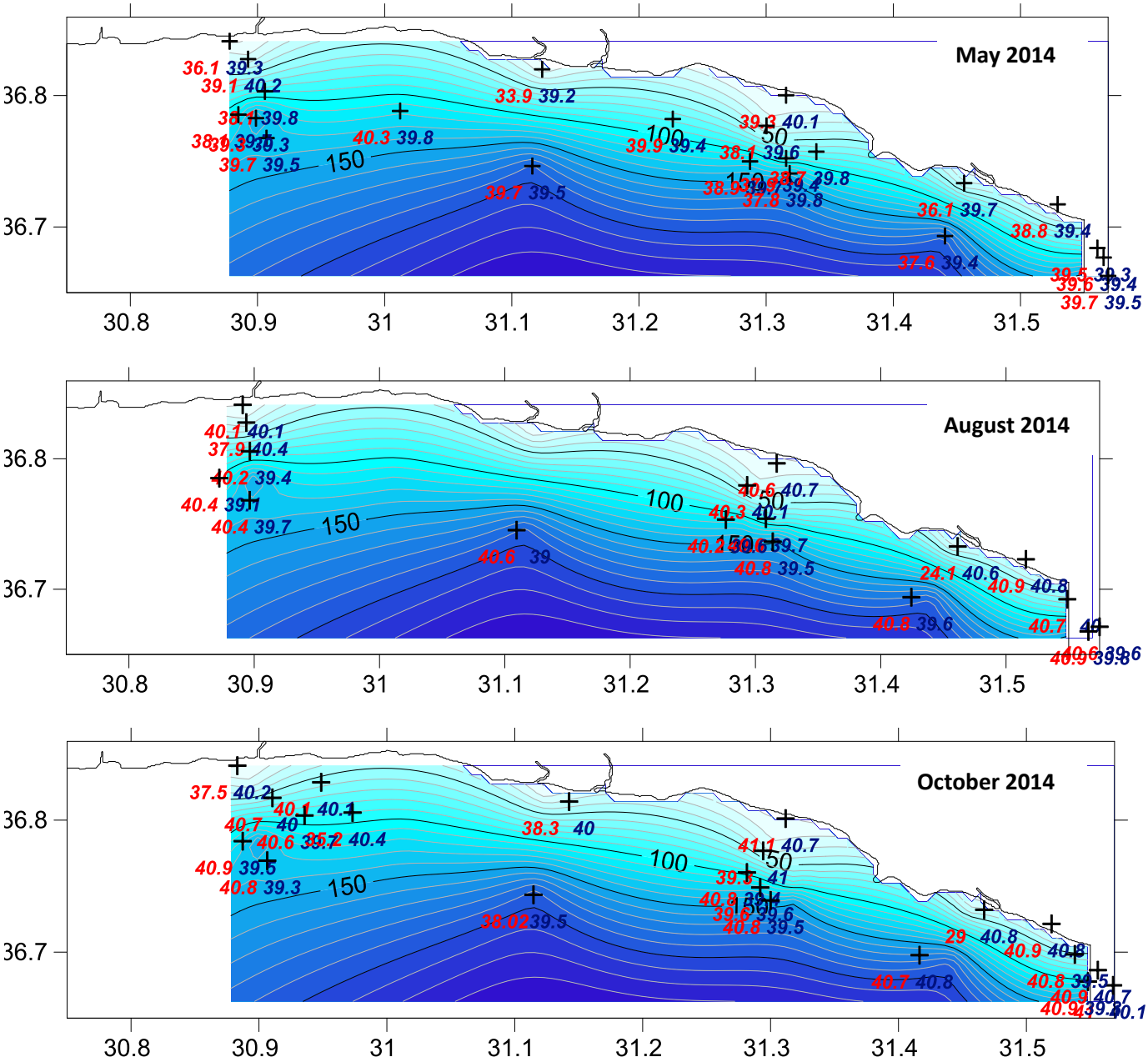


Figure 8 Spatio-temporal distribution of sea surface (red) and near bottom temperature (blue) values (^{0}C). (Black numbers are depth in meters).

Salinity did not vary relevantly with depth, nevertheless some exception. Sea Surface Salinity of station in front of Manavgat river (T3_10) was significantly lower than other stations. The

SSS of this station was 36.1 psu in May, 24.1 psu in August, 29 psu in October and 34.5 psu February. In May, SSS increased from inshore to offshore passing from 36.1 to 40.3 psu. However, NBS did not display this trend. In Figure 9, is shown the very low SSS in May (33.9 psu) of the station close to Manavgat river (T3_10) . SSS in October and in August were homogeneous more among the depth, showing a small range between SSS and NBS for each station. Spatial distribution of salinity was similar to that of the temperatures in February, but regarding salinity the range of differences was less than temperature, detecting a slight increase from inshore to offshore.



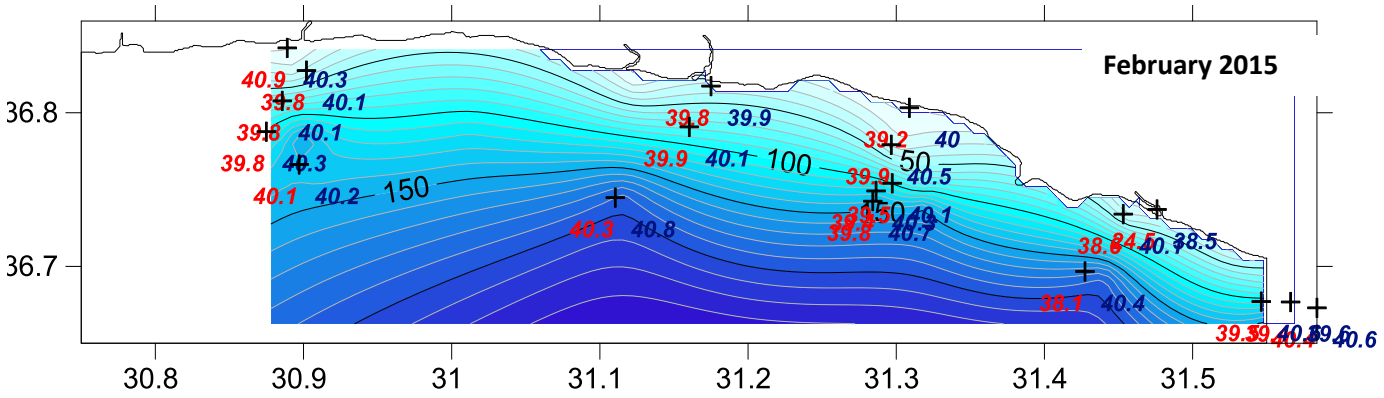
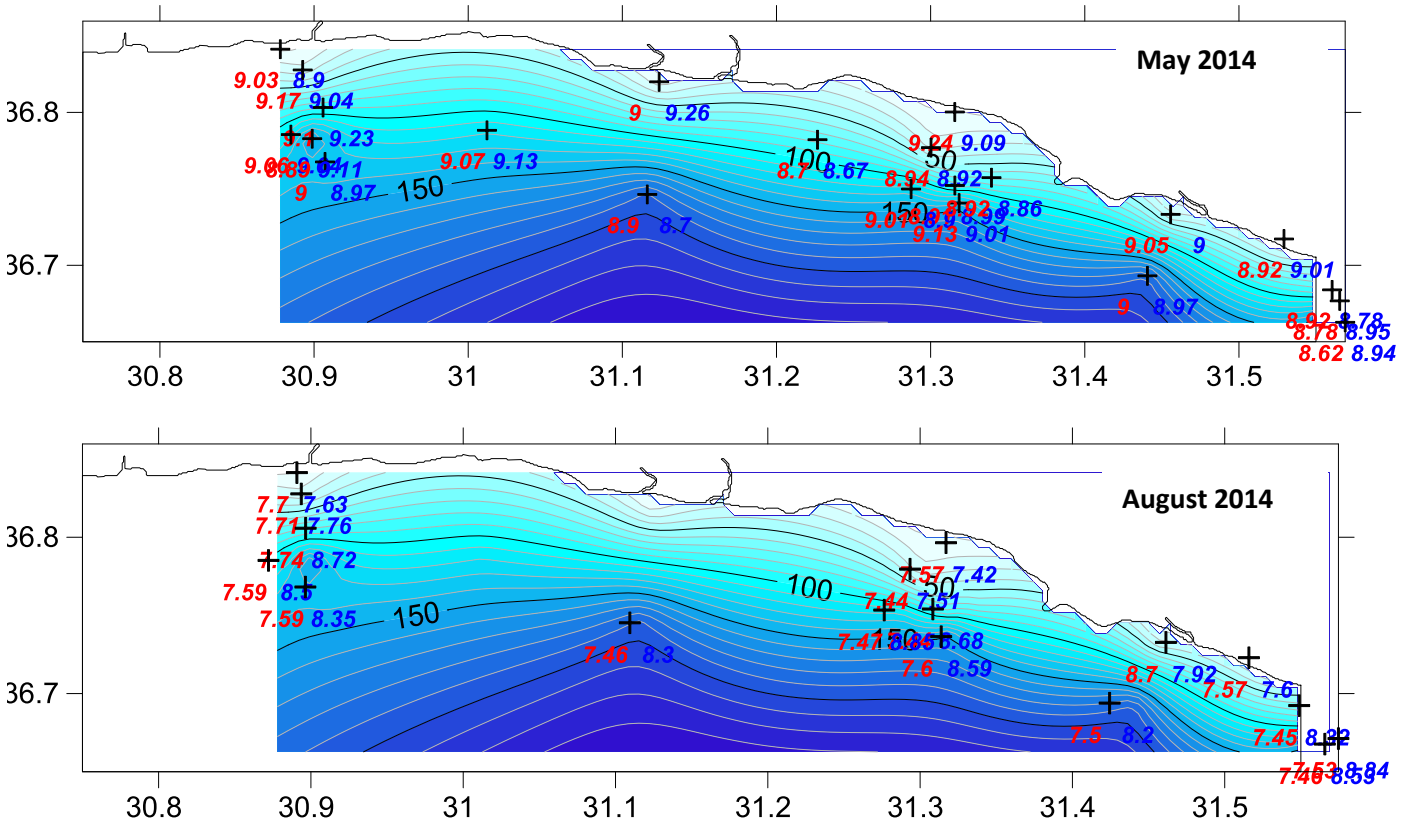


Figure 9 Spatio-temporal distribution of sea surface (red) and near bottom salinity (blue) values (PSU). (Black numbers are depth in meters).

The Sea Surface Oxygen (SSOx) and Near Bottom Oxygen (NBOx) were significantly different among seasons and bottom depths, showing for each season a decreasing trend from coast seaward (fig 10). The SSOx reached the peak value in colder waters in May (9.24 for SSOx and 9.26 for NBOx) and February (9.84 for SSOx and 9.44 for NBOx) and it was significantly lower in August (7.46 for SSOx and 7.76 for NBOx).



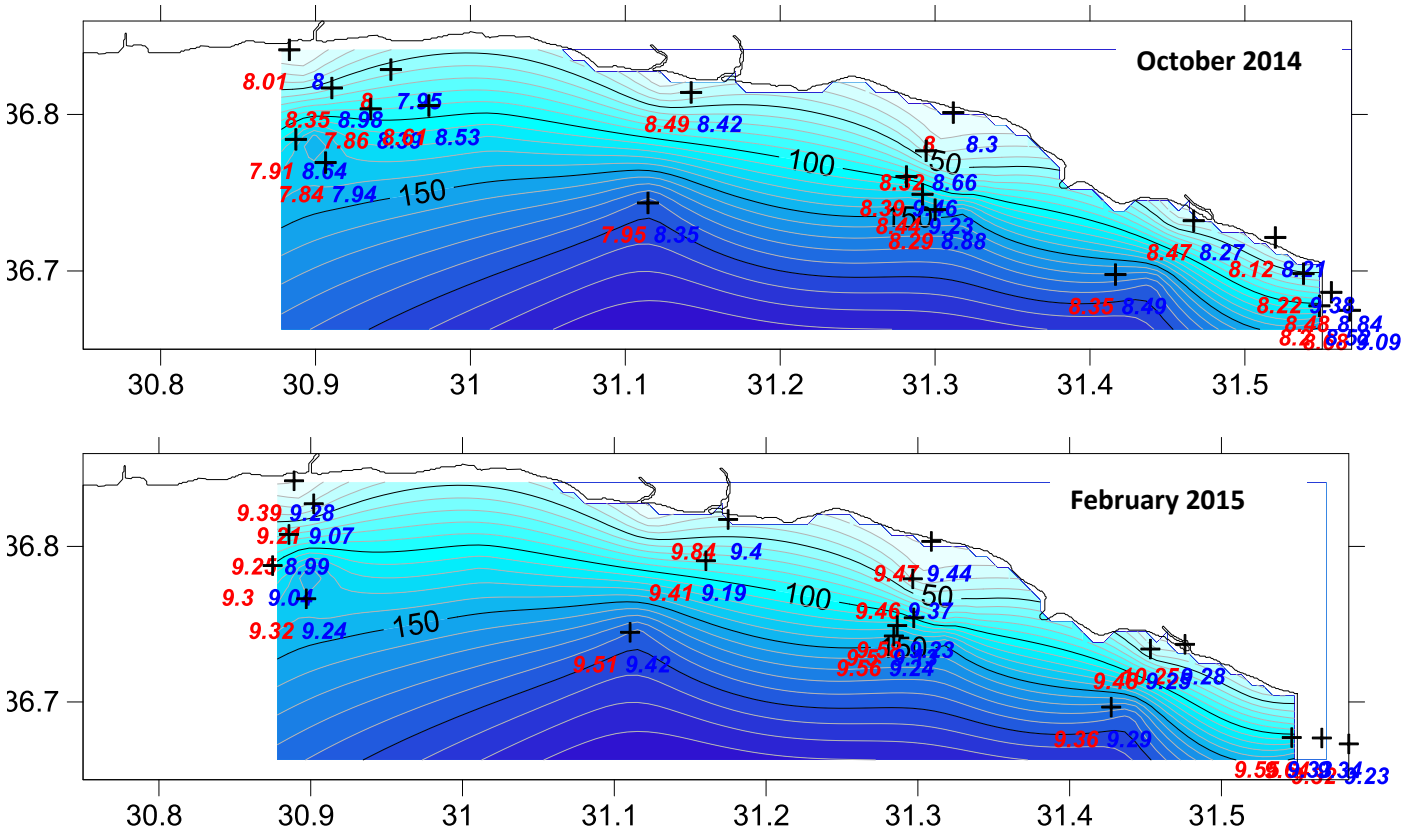


Figure 10 Spatio-temporal distribution of sea surface (red) and near bottom oxygen (blue) values (mg $L^{-}{}_{1}$). (Black numbers are depth in meters).

The Sea Surface Density (SSD) and Near Bottom Density (NBD) showed a decreasing trend from coast seaward (Figure 11). The density of the sampling station in front of Manavgat river was very low compared to the others (Figure 11). Although the density patterns appeared to be more complex in October as compared with those of the other seasons, SSD decreased from 25.23 to 27.75 passing form the inshore waters to the offshore waters.

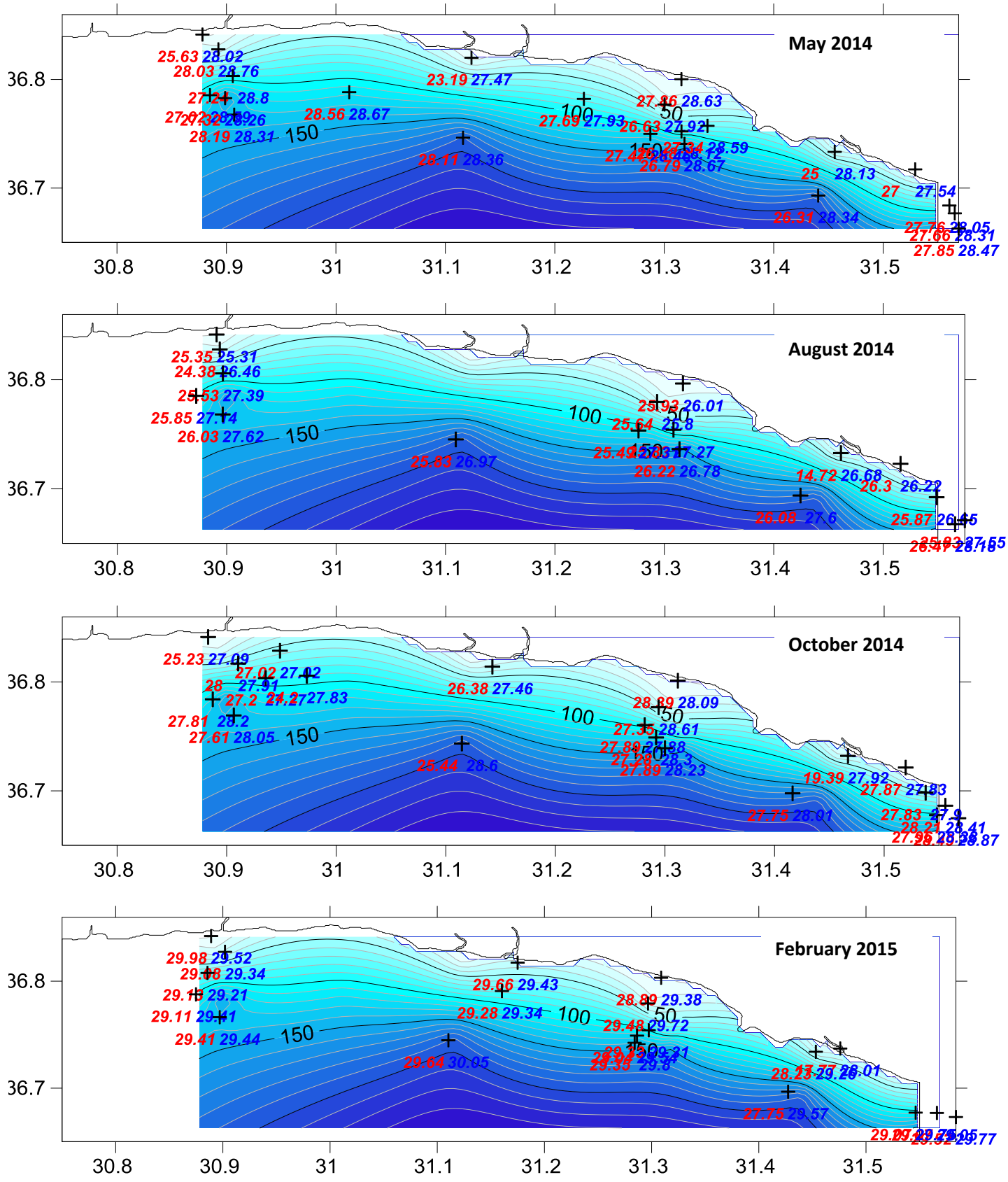


Figure 11 Spatio-temporal distribution of sea surface (red) and near bottom density (blue) values (sigma-t). (Black numbers are depth in meters).

3.2 Distribution of diversity

The four surveys in the Antalya Gulf allowed the sampling of 58 crustacean species belonging to three orders (Stomatopoda, Isopoda and Decapoda) and NN families. Eighteen species were non native species (table 3).

Table 3 Crustacean species collected from Antalya Gulf, with order and family, and with their origin (MS: Mediterranean Sea; AS: Alien Species).

Family/Order	Genus and species	Origin	Family/Order	Genus and species	Origin
DECAPODA			**DECAPODA**		
Alpheidae	*Alpheus migrans* (Lewinsohn & Holthuis, 1978)	AS	Parthenopidae	*Derilambrus angulifrons* (Latreille, 1825)	MS
Alpheidae	*Alpheus rapacida* (de Man, 1908)	AS	Penaeidae	*Farfantepenaeus aztecus* (Ives, 1891)	AS
Calappidae	*Calappa granulata* (Linnaeus, 1758)	MS	Penaeidae	*Marsupenaeus japonicus* (Spence Bate, 1888)	AS
Crangonidae	*Aegaeon cataphractus* (Olivi, 1792)	MS	Penaeidae	*Metapenaeopsis aegyptia* (Galil & Golani, 1990)	AS
Crangonidae	*Aegaeon lacazei* (Gourret, 1887)	MS	Penaeidae	Metapenaeopsis m. *consobrina*(Nobili, 1904)	AS
Diogenidae	*Dardanus arrossor* (Herbst, 1796)	MS	Penaeidae	*Metapenaeus monoceros* (Fabricius, 1798)	AS
Diogenidae	*Dardanus calidus* (Risso, 1827)	MS	Penaeidae	*Parapenaeus longirostris* (Lucas, 1846)	MS
Diogenidae	*Paguristes eremita* (Linnaeus, 1767)	MS	Penaeidae	*Penaeus hathor* (Burkenroad, 1959)	AS
Dorippidae	*Medorippe lanata* (Linnaeus, 1767)	MS	Penaeidae	*Penaeus kerathurus* (Forskål, 1775)	MS
Dromiidae	*Dromia personata* (Linnaeus, 1758)	MS	Penaeidae	*Penaeus semisulcatus* (De Haan, 1844)	AS
Epialtidae	*Pisa armata* (Latreille, 1803)	MS	Penaeidae	*Trachysalambria curvirostris* (Stimpson, 1860)	AS
Goneplacidae	*Goneplax rhomboides* (Linnaeus, 1758)	AS	Pilumnidae	Pilumnus spinifer (H. Milne Edwards, 1834)	MS
Hippolytidae	*Lysmata seticaudata* (Risso, 1816)	MS	Portunidae	*Charybdis hellerii* (A. Milne-Edwards, 1867)	AS
Homolidae	*Homola barbata* (Fabricius, 1793)	MS	Portunidae	*Charybdis longicollis* (Leene, 1938)	AS
Inachidae	*Inachus dorsettensis* (Pennant, 1777)	MS	Portunidae	*Gonioinfradens paucidentatus* (Milne-Edwards, 1861)	MS

Inachidae	*Macropodia longirostris* (Fabricius, 1775)	MS	Portunidae	*Liocarcinus depurator* (Linnaeus, 1758)	MS
Inachidae	*Macropodia tenuirostris* (Leach, 1814)	MS	Portunidae	*Portunus hastatus* (Linnaeus, 1767)	MS
Latreillidae	*Latreillia elegans* (Roux, 1830)	MS	Portunidae	*Portunus pelagicus* (Linnaeus, 1758)	AS
Leucosiidae	*Ixa monodi* (Holthuis, 1956)	AS	Portunidae	*Thalamita poissonii* (Audouin, 1826)	AS
Majidae	*Maja goltziana* (d'Oliveira, 1888)	MS	Processidae	*Processa edulis* (Risso, 1816)	MS
Majidae	*Maja squinado* (Herbst, 1788)	MS	Sicyoniidae	*Sicyonia lancifer* (Olivier, 1811)	AS
Paguridae	*Anapagurus chiroacanthus* (Lilljeborg, 1856)	MS	Solenoceridae	*Solenocera membranacea* (Risso, 1816)	MS
Paguridae	*Anapagurus petiti* (Dechancé & Forest, 1962)	MS	**ISOPODA**		
Paguridae	*Pagurus alatus* (Fabricius, 1775)	MS	Aegidae	*Rocinela dumerilii* (Lucas, 1849)	MS
Paguridae	*Pagurus excavatus* (Herbst, 1791)	MS	Cymothoidae	*Cerotothoa oestroides* (Risso, 1816)	MS
Paguridae	*Pagarus prideaux* (Leach, 1815)	MS	Cymothoidae	*Nerocila bivittata* (Risso, 1816)	MS
Palinuridae	*Palinurus elephas* (Fabricius, 1787)	MS	**STOMATOPODA**		
Pandalidae	*Chlorotocus crassicornis* (A. Costa, 1871)	MS	Parasquillidae	*Parasquilla ferussaci* (Roux, 1828)	MS
Pandalidae	*Plesionika edwardsii* (Brandt, 1851)	MS	Squillidae	*Erugosquillamassavensis* (Kossmann, 1880)	AS
Pandalidae	*Plesionika heterocarpus* (A. Costa, 1871)	MS	Squillidae	*Squilla mantis* (Linnaeus, 1758)	MS

The annual distribution of dominance (D), the frequency of occurrence (FO)and the numerical occurrence of the crustacean species were given in table 4.

Looking the annual dominance, no constant species were found in the study area, nevertheless some crustacean species were identified as common in the area. The most dominant species were *Pagurus prideaux* (Leach, 1815) and *Parapenaeus longirostris* (Lucas, 1846) both occurring in 38.46% of stations with a frequency of occurrence of 7.83%. These were followed by *Charybdis longicollis* (Leene, 1938) that occurred in 33.33 % of stations (FO = 6.79%) and *Marsupenaeus japonicus* (Spence Bate, 1888) that occurred in 26.92% of stations (FO = 5.48%). Most of the species were considered rare and 10 species were very rare, summing up at 17.25% of total species and being recorded only in a few stations (D% 1.28% and FO 0.26%).

Table 4. Annual distribution of dominance (D in %), frequency of occurrence (FO in %), numerical occurrence for abundance (NO1 in %), for biomass (NO2 in %) percentage of crustacean species.

Order/Species	D% MAY	FO % MAY	NO1 % MAY	NO2 % MAY	D% AUG	FO% AUG	NO1% AUG	NO2 % AUG	D% OCT	FO% OCT	NO1% OCT	NO2 % OCT	D% FEB	FO% FEB	NO1 % FEB	NO2 % FEB	D% YEAR	FO% YEAR	NO1 % YEAR	NO2 % YEAR
Decapoda																				
Aegaeon cataphractus	13.64	3.06	0.04	0.34	6.25	2.33	0.03	0.14	23.81	3.82	0.17	0.99	5.26	0.90	0.02	0.10	12.82	2.61	0.09	0.52
Aegaeon lacazei	0	0	0	0	0	0	0	0	0	0	0	0	5.26	0.90	0.13	0.70	1.28	0.26	0.02	0.13
Alpheus migrans	0	0	0	0	0	0	0	0	0	0	0	0	5.26	0.90	0.00	0.12	1.28	0.26	0.00	0.02
Alpheus rapacida	0	0	0	0	0	0	0	0	4.762	0.763	0.031	0.038	0	0	0	0	1.28	0.26	0.01	0.01
Anapagurus chiroacanthus	0	0	0	0	0	0	0	0	0	0	0	0	5.26	0.90	0.01	0.12	1.28	0.26	0.00	0.02
Anapagurus petiti	0	0	0	0	0	0	0	0	4.76	0.76	0.05	0.19	5.26	0.90	0.01	0.15	2.56	0.52	0.02	0.10
Calappa granulata	18.18	4.08	2.39	0.18	12.50	4.65	7.53	0.26	19.05	3.05	4.40	0.22	10.53	1.80	15.30	0.56	15.38	3.13	6.04	0.28
Charybdis helleri	0	0	0	0	0	0	0	0	0	0	0	0	10.53	1.80	0.97	0.44	2.56	0.52	0.18	0.09
Charybdis longicollis	36.36	8.16	4.42	3.63	12.5	4.65	2.22	1.16	42.86	6.87	18.99	13.77	36.84	6.31	4.79	3.26	33.33	6.79	10.16	7.17
Chlorotocus crassicornis	4.55	1.02	0.02	0.16	0	0	0	0	9.52	1.53	0.03	0.26	5.26	0.90	0.01	0.08	5.13	1.04	0.02	0.17
Dardanus arrossor	18.18	4.08	0.27	0.44	0	0	0	0	4.76	0.76	0.03	0.09	10.53	1.80	0.07	0.15	8.97	1.83	0.11	0.20
Dardanus calidus	0	0	0	0	6.25	2.33	0.18	0.15	4.76	0.76	0.08	0.05	0	0	0	0	2.56	0.52	0.05	0.04
Derilambrus angulifrons	18.18	4.08	0.32	0.34	25	9.30	0.93	1.05	23.81	3.82	0.15	0.34	21.05	3.60	0.48	0.88	21.79	4.44	0.34	0.52
Dromia personata	9.09	2.04	0.23	0.09	0	0	0	0	9.52	1.53	0.19	0.50	10.53	1.80	0.19	0.20	7.69	1.57	0.18	0.26
Farfantepenaeus aztecus	9.09	2.04	1.16	0.31	6.25	2.33	0.67	0.14	38.10	6.11	6.83	1.49	10.53	1.80	1.83	0.23	16.67	3.39	3.52	0.73
Goneplax rhomboides	4.55	1.02	0.01	0.05	0	0	0	0	9.52	1.53	0.03	0.25	0	0	0	0	3.85	0.78	0.01	0.11
Gonioinfradens paucidentatus	0	0	0	0	0	0	0	0	4.76	0.76	0.04	0.04	0	0	0	0	1.28	0.26	0.02	0.01
Homola barbata	27.27	6.12	0.31	0.94	0	0	0	0	9.52	1.53	0.02	0.09	21.05	3.60	0.32	1.08	15.38	3.13	0.16	0.54
Inachus dorsettensis	22.73	5.10	0.07	0.33	0	0	0	0	0	0	0	0	15.79	2.70	0.04	0.33	10.26	2.09	0.03	0.17
Ixa monodi	0	0	0	0	12.5	4.65	0.21	0.33	4.76	0.76	0.00	0.03	5.26	0.90	0.03	0.12	5.13	1.04	0.03	0.07
Latreillia elegans	4.55	1.02	0.00	0.03	0	0	0	0	0	0	0	0	10.53	1.80	0.01	0.38	3.85	0.78	0.00	0.08
Liocarcinus depurator	0	0	0	0	18.75	6.98	0.74	1.71	9.52	1.53	0.04	0.07	10.53	1.80	0.08	0.15	8.97	1.83	0.10	0.23
Lysmata seticaudata	0	0	0	0	0	0	0	0	4.76	0.76	0.01	0.12	0	0	0	0	1.28	0.26	0.00	0.05
Macropodia longirostris	9.09	2.04	0.04	0.75	0	0	0	0	0	0	0	0	10.53	1.80	0.01	0.20	5.13	1.04	0.02	0.28
Macropodia tenuirostris	4.55	1.02	0.01	0.12	6.25	2.33	0.01	0.18	4.76	0.76	0.00	0.04	10.53	1.80	0.01	0.17	6.41	1.31	0.01	0.10
Maja goltziana	9.09	2.04	0.22	0.09	0	0	0	0	0	0	0	0	5.26	0.90	0.15	0.10	3.85	0.78	0.10	0.05
Maja sp.	0	0	0	0	6.25	2.33	0.08	0.18	4.76	0.76	0.02	0.05	0	0	0	0	2.56	0.52	0.01	0.04
Maja squinado	0	0	0	0	6.25	2.33	4.09	0.25	19.05	3.05	4.56	0.34	5.26	0.90	3.26	0.23	7.69	1.57	2.83	0.20
Mansupenaeus japonicus	13.64	3.06	2.53	0.52	6.25	2.33	4.06	0.70	23.81	3.82	6.65	4.20	42.11	7.21	18.70	4.93	21.79	4.44	7.27	2.79
Medorippe lanata	36.36	8.16	3.02	1.54	18.75	6.98	1.65	1.16	23.81	3.82	0.76	0.62	26.32	4.50	1.58	1.30	26.92	5.48	1.71	1.10
Metapenaeopsis aegyptia	4.55	1.02	0.01	0.04	0	0	0	0	14.29	2.29	3.58	7.45	10.53	1.80	0.14	0.47	7.69	1.57	1.47	2.95
Metapenaeopsis mogiensis consobrina	0	0	0	0	0	0	0	0	4.76	0.76	0.01	0.04	5.26	0.90	0.02	0.05	2.56	0.52	0.01	0.02
Metapenaeus monoceros	4.55	1.02	0.08	0.04	0	0	0	0	4.76	0.76	0.03	0.03	5.26	0.90	0.29	0.07	3.85	0.78	0.09	0.04
Pagurus alatus	0	0	0	0	0	0	0	0	0	0	0	0	5.26	0.90	0.04	0.09	1.28	0.26	0.01	0.02
Pagurus excavatus	13.64	3.06	0.68	2.22	0	0	0	0	4.76	0.76	0.01	0.04	21.05	3.60	0.37	0.76	10.26	2.09	0.29	0.87
Pagurus prideaux	40.91	9.18	5.25	11.91	25	9.30	4.59	15.02	61.90	9.92	6.21	23.02	21.05	3.60	7.56	23.47	38.46	7.83	5.99	18.70
Pagurus sp.	0	0	0	0	0	0	0	0	4.76	0.76	0.24	1.00	0	0	0	0	1.28	0.26	0.10	0.38
Paguristes eremita	4.55	1.02	0.01	0.08	0	0	0	0	4.76	0.76	0.01	0.05	0	0	0	0	2.56	0.52	0.00	0.04
Parapenaeus longirostris	31.82	7.14	69.71	66.19	43.75	16.28	71.11	69.66	42.86	6.87	29.00	32.02	36.84	6.31	20.48	44.73	38.46	7.83	44.47	49.38
Penaeus hathor	4.55	1.02	0.43	0.09	0	0	0	0	19.05	3.05	4.38	2.40	36.84	6.31	4.90	1.99	15.38	3.13	2.79	1.33
Penaeus kerathurus	4.55	1.02	0.57	0.08	6.25	2.33	0.45	0.29	14.29	2.29	1.67	0.65	0	0	0	0	6.41	1.31	0.90	0.30
Penaeus semisulcatus	0	0	0	0	12.5	4.65	0.36	0.30	19.05	3.05	3.00	0.58	26.32	4.50	11.03	1.57	14.10	2.87	3.25	0.56
Pilumnus spinifer	0	0	0	0	0	0	0	0	0	0	0	0	5.26	0.90	0.00	0.08	1.28	0.26	0.00	0.01
Pisa armata	31.82	7.14	0.27	0.77	6.25	2.33	0.04	0.19	23.81	3.82	0.18	0.90	21.05	3.60	0.84	3.03	21.79	4.44	0.31	1.19
Plesionika edwardsii	4.55	1.02	2.67	1.41	6.25	2.33	0.46	2.77	9.52	1.53	1.65	3.23	10.53	1.80	0.15	0.79	7.69	1.57	1.58	2.13
Plesionika heterocarpus	9.09	2.04	0.83	6.75	0	0	0	0	4.76	0.76	0.03	0.30	15.79	2.70	0.70	4.09	7.69	1.57	0.40	3.07
Portunus hastatus	0	0	0	0	0	0	0	0	4.76	0.76	0.32	0.08	5.26	0.90	0.33	0.33	2.56	0.52	0.19	0.09
Portunus pelagicus	9.09	2.04	3.76	0.10	0	0	0	0	4.76	0.76	4.92	0.15	5.26	0.90	2.93	0.12	5.13	1.04	3.71	0.11
Processa edulis	0	0	0	0	0	0	0	0	4.76	0.76	0.02	0.16	0	0	0	0	1.28	0.26	0.01	0.06
Sicyonia lancifer	0	0	0	0	0	0	0	0	4.76	0.76	0.02	0.05	5.26	0.90	0.06	0.13	2.56	0.52	0.02	0.04
Solenocera membranacea	0	0	0	0	0	0	0	0	9.52	1.53	0.04	0.21	5.26	0.90	0.09	0.23	3.85	0.78	0.03	0.13
Thalamita poissonii	0	0	0	0	12.50	4.65	0.50	4.08	9.52	1.53	0.56	2.60	15.79	2.70	0.29	0.91	8.97	1.83	0.33	1.59
Trachysalambria curvirostris	0	0	0	0	12.50	4.65	0.11	0.30	9.52	1.53	0.12	0.55	0	0	0	0	5.13	1.04	0.06	0.24
Phyllosoma Palinurus elephas	0	0	0	0	0	0	0	0	4.76	0.76	0.02	0.10	0	0	0	0	1.28	0.26	0.01	0.04
Isopoda																				
Cerotothoa oestroides	0	0	0	0	0	0	0	0	4.76	0.76	0.01	0.16	0	0	0	0	1.28	0.26	0.00	0.06
Nerocila bivittata	0	0	0	0	0	0	0	0	0	0	0	0	5.26	0.90	0.07	0.28	1.28	0.26	0.01	0.05
Rocinela dumerilii	4.55	1.02	0.01	0.03	0	0	0	0	0	0	0	0	5.26	0.90	0.03	0.12	2.56	0.52	0.01	0.03
Stomatopoda																				
Erugosquilla massavensis	18.18	4.08	0.69	0.43	0	0	0	0	14.29	2.29	0.40	0.36	10.53	1.80	1.70	0.72	11.54	2.35	0.69	0.42
Parasquilla ferussaci	0	0	0	0	0	0	0	0	4.76	0.76	0.02	0.04	0	0	0	0	1.28	0.26	0.01	0.02
Squilla mantis	0	0	0	0	0	0	0	0	9.52	1.53	0.48	0.07	0	0	0	0	2.56	0.52	0.19	0.03

3.2.1 Distribution of number of species

Three orders of Crustacea were observed (Fig 12). Decapoda showed the highest species number (54) follow by Stomatopoda order and Isopoda order (both with 3 species).

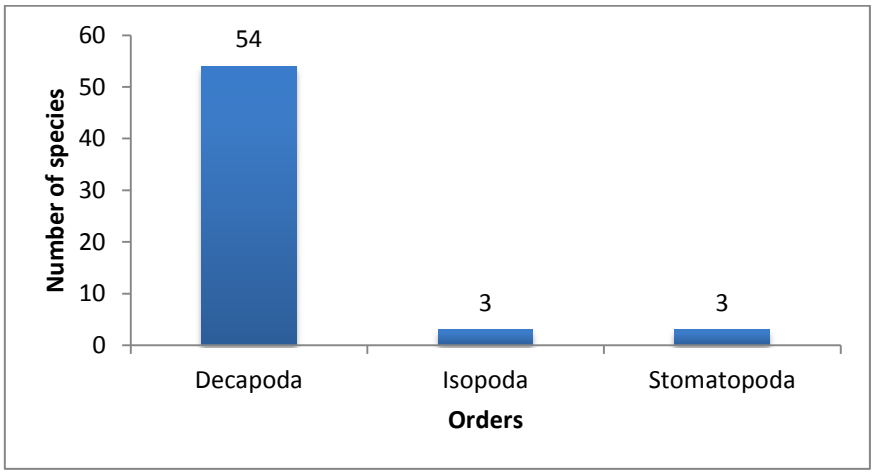


Figure 12 Number of species of each order of Crustacea

Twenty-four families belonging to Decapoda were found (fig 13). The richest families in number of species collected were Penaeidae and Portunidae, respectively with 10 and 7 species. These were followed by Paguridae family with 6 species. In the family Portunidae, *Charybdis longicollis* was the most dominant species (33.33%) with a frequency of occurrence was 6.79%.

The family Majidae was represented by 3 species, where the most frequent was the commercial crab *Maja squinado* with a frequency of occurrence of 1.57%. Furthermore, 15 families were composed of only one species each, and among these *Medorippe lanata* (Linnaeus, 1767; Dorippidae) was the most frequently observed (26.92%). Ten species of decapoda were observed in a low frequency (0.26 % for each).

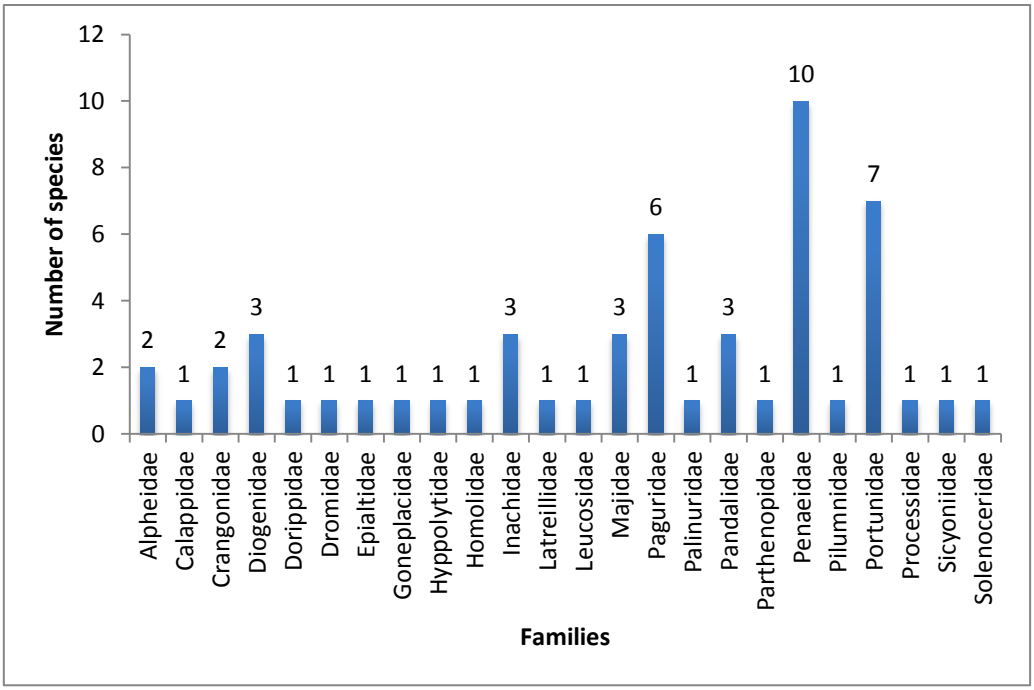


Figure 13 Number of species of each family of Decapoda

The number of species decreased from May to August, and then increased in colder seasons when it peaked the maximum value in October with 48 species. In February the number slightly decreased to 45 species (Fig 14) with lowest values registered in May (31) and in August (21).

Figure 15 showed the number of species for each order of Crustacea registered in each season.

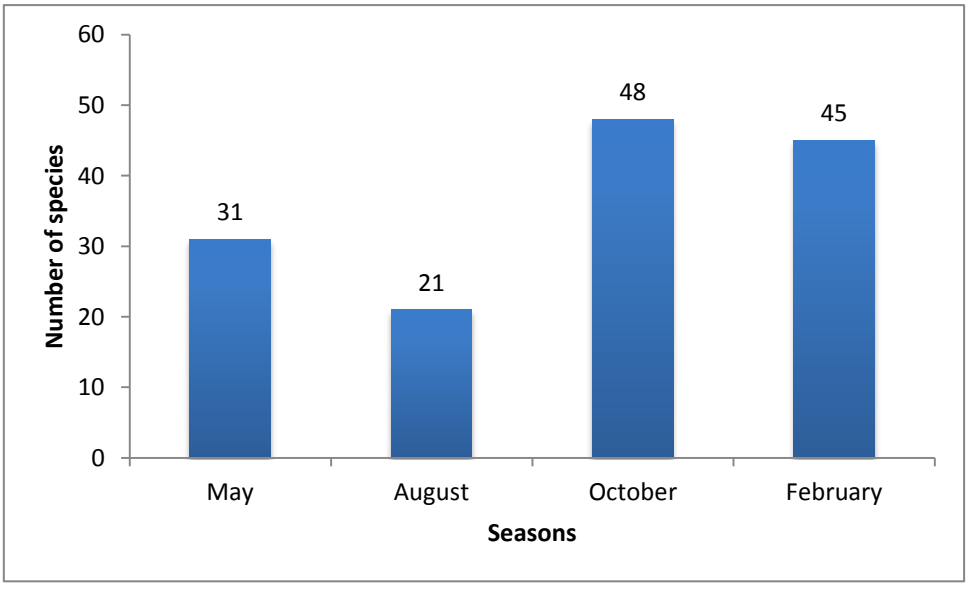


Figure 14 Distribution of number of species of Crustacea in the seasons.

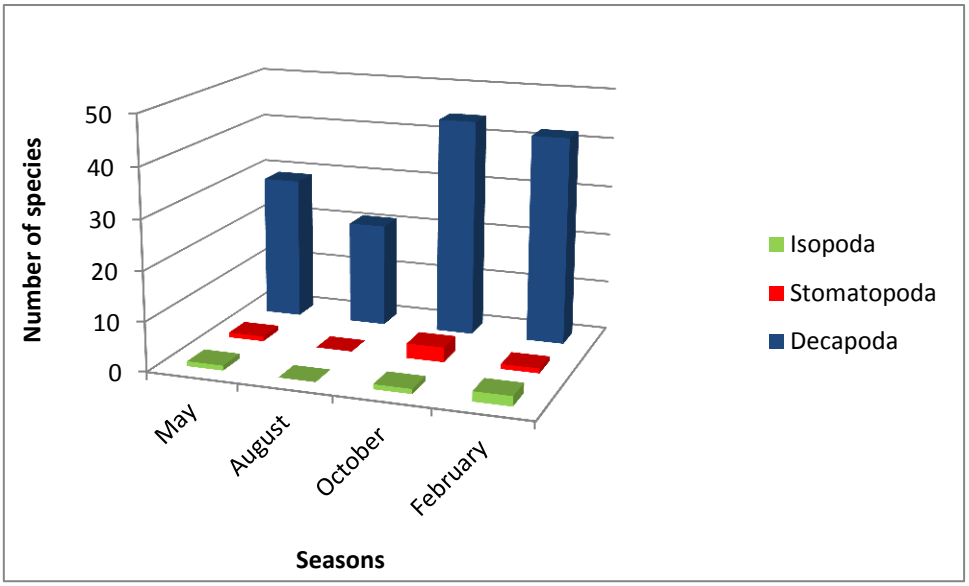


Figure 15 Number of species of each order of Crustacea in the seasons.

The number of species of each family of Decapoda for each season was illustrated in Figure 16. Furthermore, looking seasonal dominance values in table 4, it appeared clear the different seasonal distribution patterns of the species. Many Penaeids were found in February such as *Marsupenaeus japonicus* (D = 42.11%; FO = 7.21%) followed by three other common species: *Parapenaeus longirostris, Penaeus hathor* (both belonging to Penaeidae) and *Charybdis longicollis* (all three with D = 36.84% and FO = 6.31%).

In May the most frequent species was *Pagurus prideaux* (D = 40.91%; FO = 9.18%.) This species was followed by two other common species, *Charybdis longicollis* and *Medorippe lanata*, both with D = 36.36% and FO = 8.16%. Lastly, *Parapenaeus longirostris* was common in this season with D= 31.82% and FO = 7.24%. In August the most frequent crustacean species was the deep-water rose shrimp *Parapenaeus longirostris* with D = 43.75% and FO = 16.28%. In August, Dominance percentage of *Derilambrus angulifrons* and *Pagurus prideaux* was at 25% and their frequency of occurrence was 9.3%.

The situation changes in October where *Pagurus prideaux* was identified as a constant species occurred in 61.90% of all stations with a frequency of occurrence of 9.92%. After this species, *Charybdis longicollis* and the penaeidae *Farfantepenaeus aztecus* were found with high D values (42.86% and 38.10% , respectively) and FO values (6.87% and 6.11%, respectively).

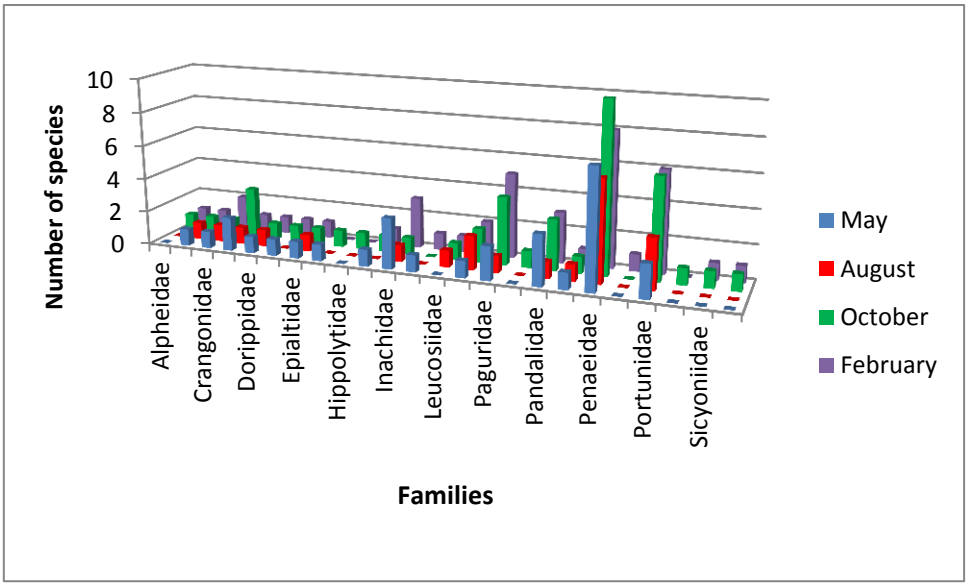


Figure 16 Number of species of each family of Decapoda in the seasons.

3.2.2 Distribution in abundance

The abundance of crustacea was estimated as individual per square meter (ind m^{-2}) (Fig 17). Decapoda was the most abundant order with 0.1133 ind m^{-2}, while the others two orders were very low in abundance, respectively with 0.002 and 0.0005 ind m^{-2}.

Based on the numerical occurrence calculated for abundance (Table 4) *Parapenaeus longirostris* was the most abundant species throughout the year with a numerical occurrence (NO) of 44.47%, and furthermore also the most abundant in each season of survey. The following abundant species across the year were *Charybdis longicollis* (NO = 10.16 %) and *Marsupenaeus japonicus* (NO = 7.27 %). Thirty-three species had NO < 0.1% all over the four seasons.

Penaeidae was the most abundant family in Decapoda order throughout the year with an abundance of 0.0665 ind m^{-2} (Fig 18), followed by Paguridae family with 0.0229 ind m^{-2}. In this family, *Pagurus prideaux* had the higher NO = 5.99%. *Calappa granulata* (Calappidae, Linnaeus, 1758) showed a high NO OF 6.04% (Table 4).

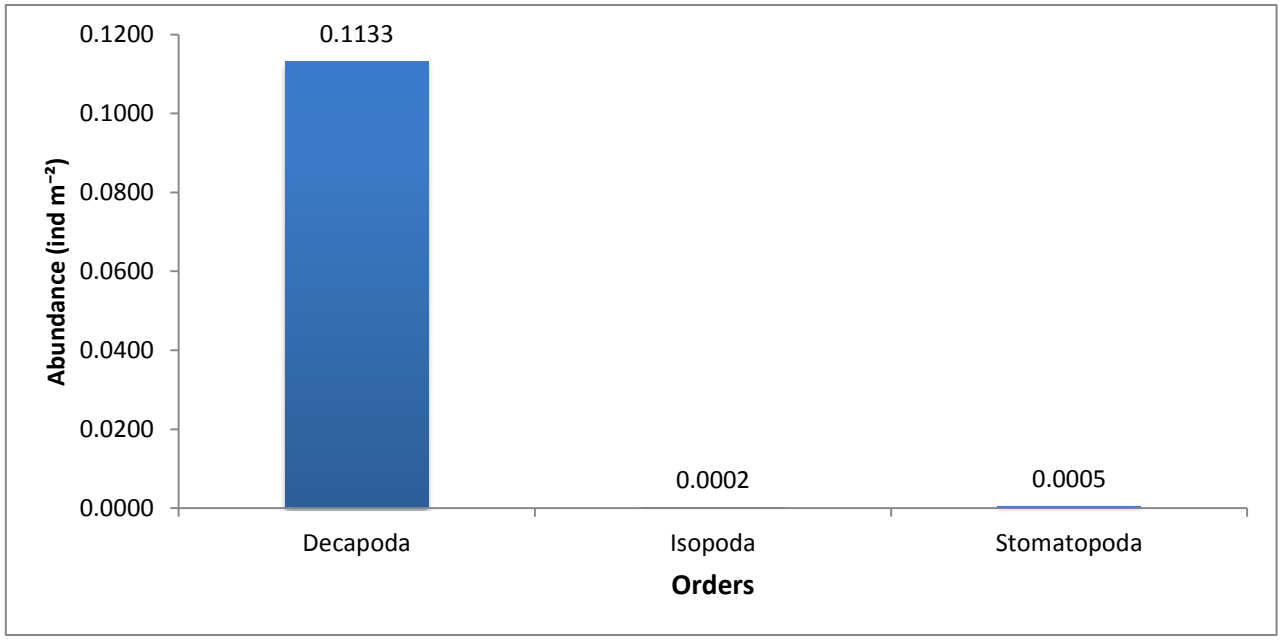


Figure 17 Abundance of each order of Crustacea

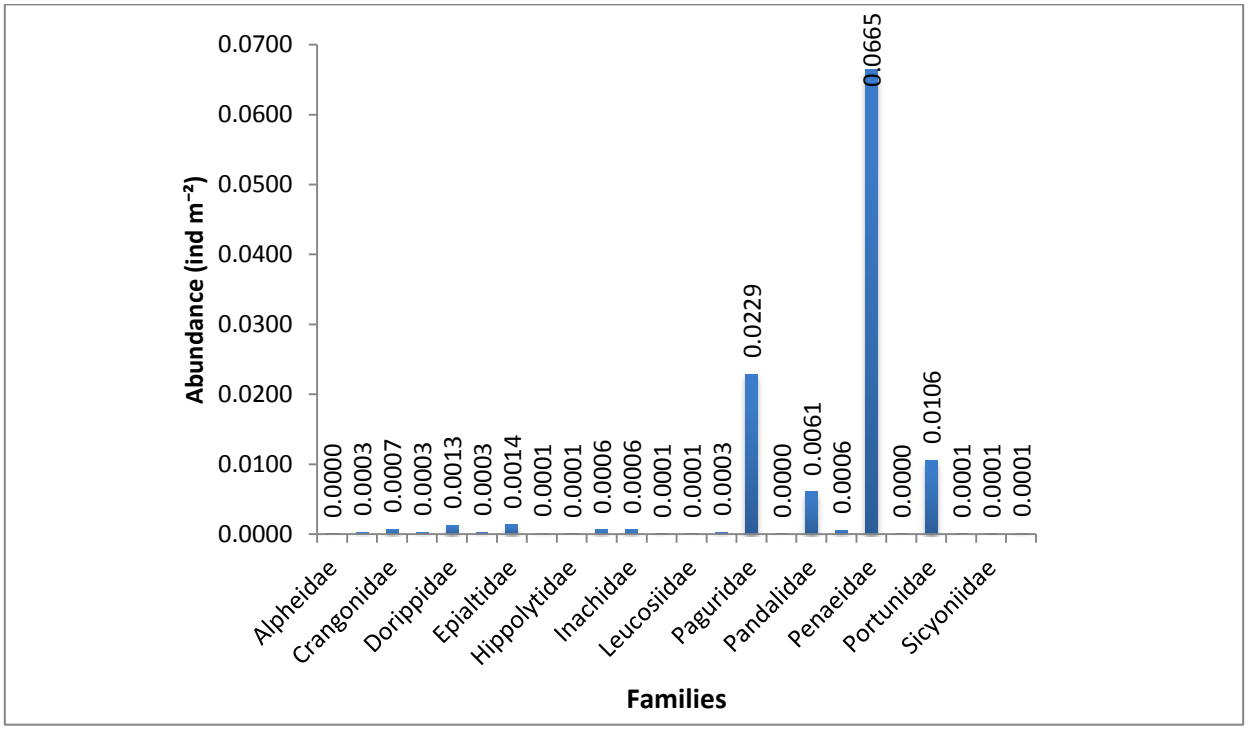


Figure 18 Abundance of each family of Decapoda

The total abundance of organisms resulted higheer in October and May than in February and August (Fig 19). Crustaceans were abundantly observed in October with 0.043 ind m^{-2} , followed by May with 0.037 ind m^{-2}, then February 0.022 ind m^{-2} and lastly August with 0.012 ind m^{-2} .

The order Decapoda was the most abundant in October (0.0432 ind m^{-2}) and was poorest in August (0.0119 ind m^{-2}), reflecting the general trend of abundance of crustaceans. Considering the other two less abundant orders (fig. 20), the Isopoda was highest in February (0.0001 ind m^{-2}) and Stomatopoda in October (0.0002 ind m^{-2}).

Regarding each family of Decapoda (Fig 21), the Penaeidae was the most abundant in all seasons. This family doesn't reflect the same trend of the abundance of each order in the four seasons, because it was highest in May than October (0.0246 and 0.0215 ind m^{-2}). The Pandalidae showed the same trend, being highest in May (0.0031 ind m^{-2}).

Pagurus prideaux was the most abundant species in May (0.02 ind m^{-2}), *Parapenaeus longirostris* in August (0.05 ind m^{-2}), *Charybdis longicollis* in October (0.03 ind m^{-2}) and *Parapenaeus longirostris* (0.04 ind m^{-2}) and *Penaeus hathor* (0.03 ind m^{-2}) in February.

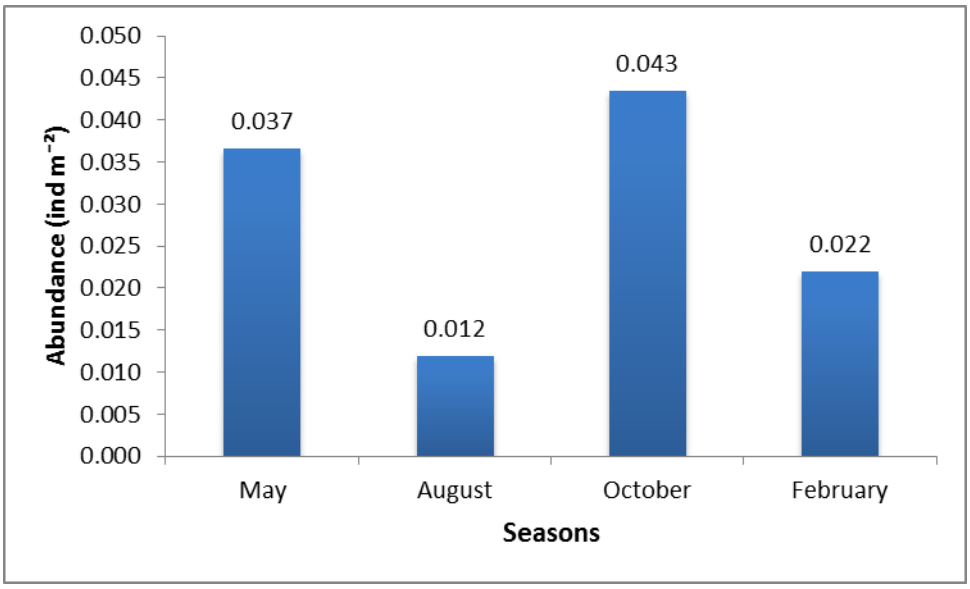


Figure 19 Distribution of abundance of Crustacea in the seasons.

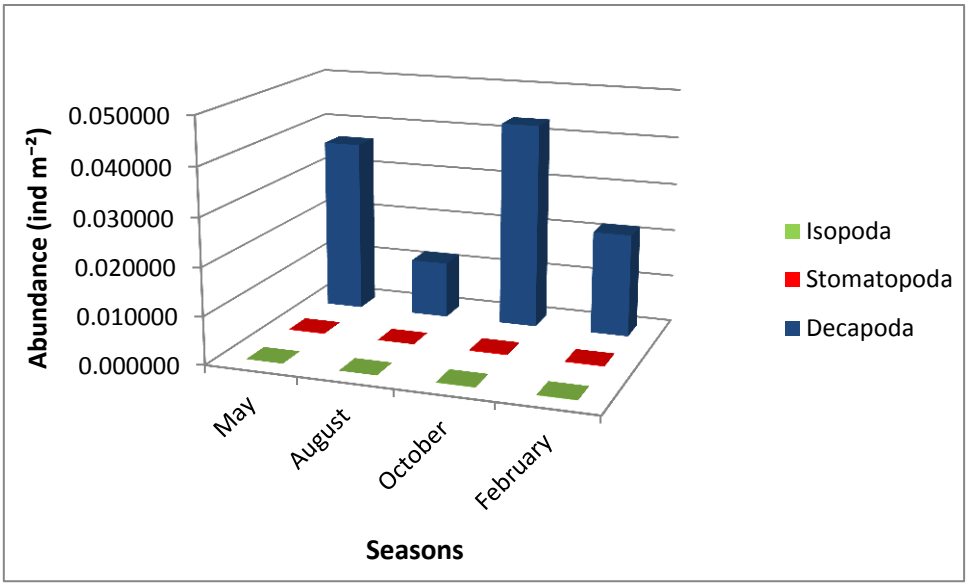


Figure 20 Abundance of each order of Crustacea in the seasons.

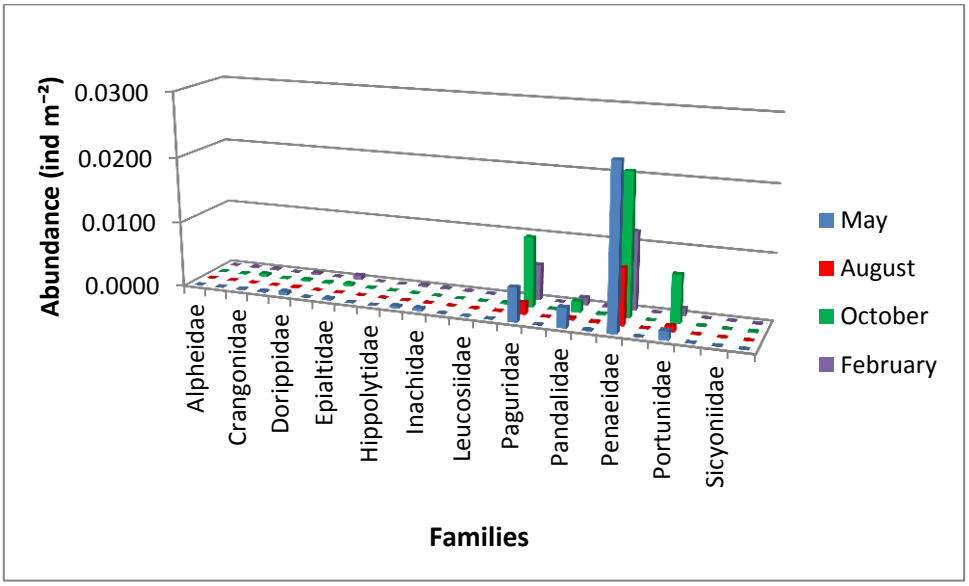


Figure 21 Abundance of each family of Decapoda in the seasons.

3.2.3 Distribution in biomass

Total biomass of Crustacea was estimated as 0.6364 g m^{-2}, being the most abundant order represented by Decapoda with 0.6305 g m^{-2} (Fig 22), followed by Stomatopoda (0.0057 g m^{-2}) and lastly Isopoda (0.0002 g m^{-2}). Referring to the numerical occurrence calculated for biomass (see table 4) *Parapenaeus longirostris* constituted 49.38% of the total biomass throughout the year.

Some of the most abundant species in biomass across the year were *Pagurus prideaux* with NO = 18.70%, *Charybdis longicollis* with NO = 7.17% and the Caridea *Plesionika heterocarpus* (NO = 3.07%). Looking the numerical occurrence for each season, it appears that the annual pattern reflects the seasons, with high NO of *Parapeneaus longirostris* and *Pagurus prideaux* in each season. *Plesionika heterocarpus* was abundantin biomass in May, representing the 6.75% of total biomass in this season. Among Decapoda, the biomass of Penaeidae was the highest with 0.4062 g m^{-2} (fig 23), followed by Portunidae family with 0.0934 g m^{-2}. Differently from the abundance pattern, the Calappidae showed relevant vaues of biomass (0.0385 g m^{-2}) only represented by *Calappa granulata* with NO = 0.89%. The species of Stomatopoda with the highest biomass was the invasive *Erugosquilla massavensis* with NO = 0.42%. Lastly, 26 species of Crustacea had NO < 0.1% all over the four seasons.

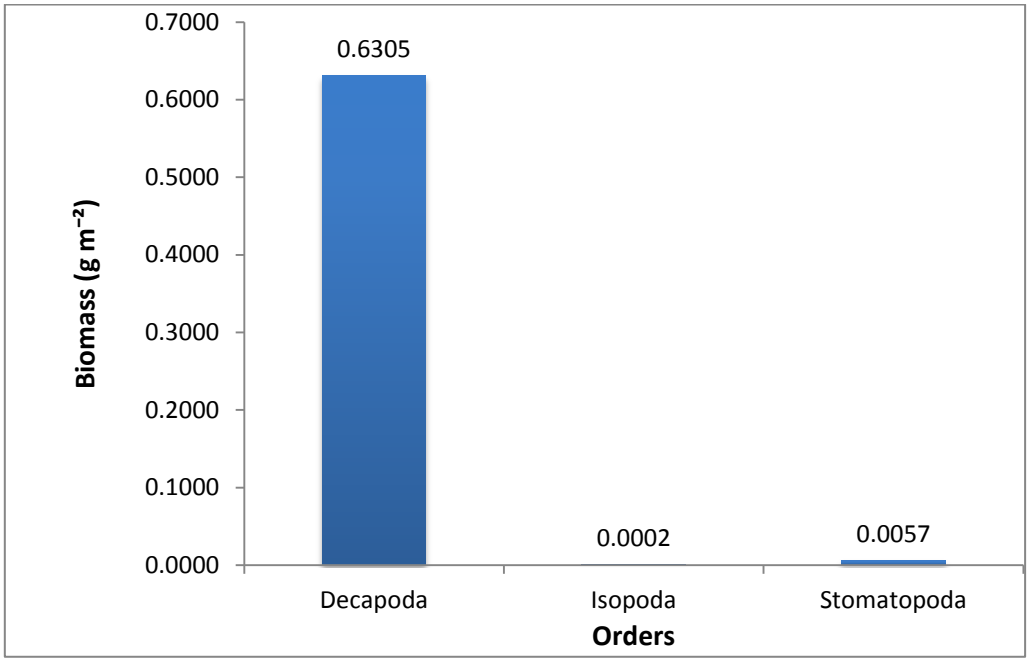


Figure 22 Biomass of each order of Crustacea

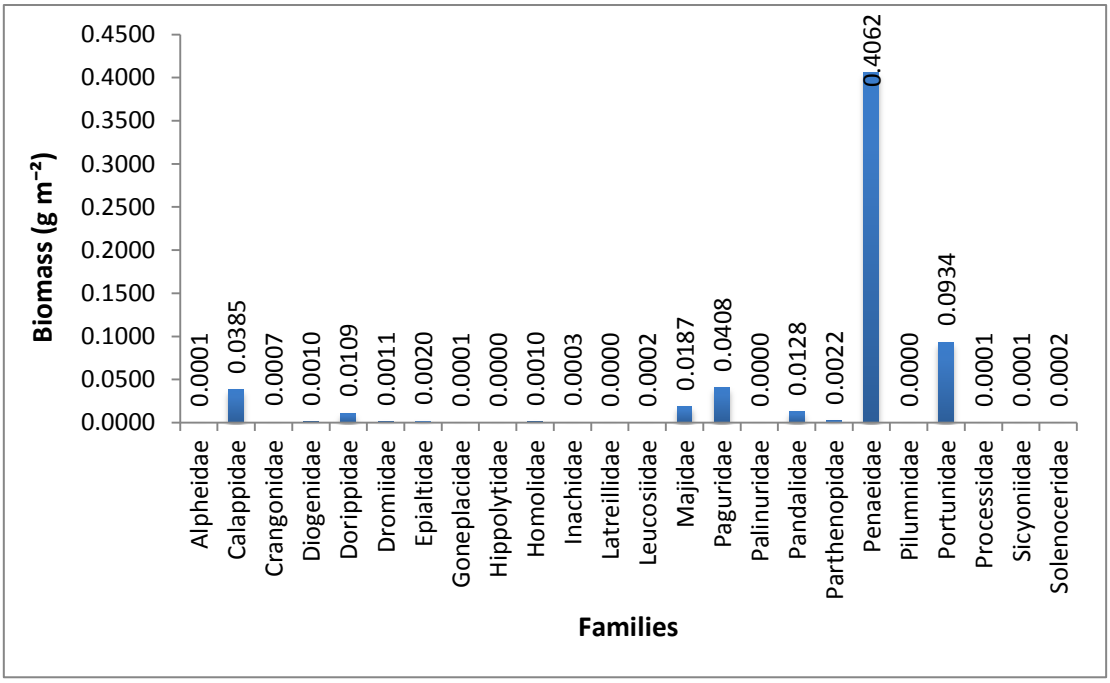


Figure 23 Biomass of each family of Decapoda

The highest value of biomass of Crustacea was found in October (0.257 g m^{-2}), followed by May with 0.202 g m^{-2}, then February 0.115 g m^{-2} and lastly August with 0.062 g m^{-2} (Fig 24). Biomass of Decapoda was higher than that of Isopoda and Stomatopoda in each season (Fig 25). At the family level, the biomasss of Decapoda in each season showed a slightly different trend comparing to that of abundance (Figure 26). Penaeidae was the most abundant in each season, showing the highest numbers in May (0.1506 g m^{-2}) and in October (0.1421 g m^{-2}). Calappidae, represented only by *Calappa granulata*, had a relevant value of biomass in February (0.0177 g m^{-2}) and in October (0.0113 g m^{-2}).

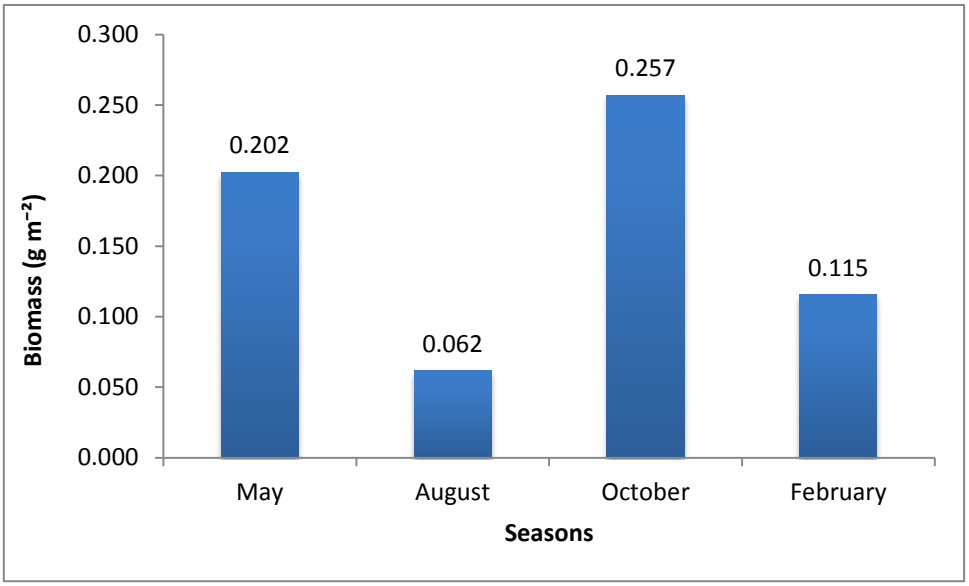


Figure 24 Distribution of biomass of Crustacea in the seasons.

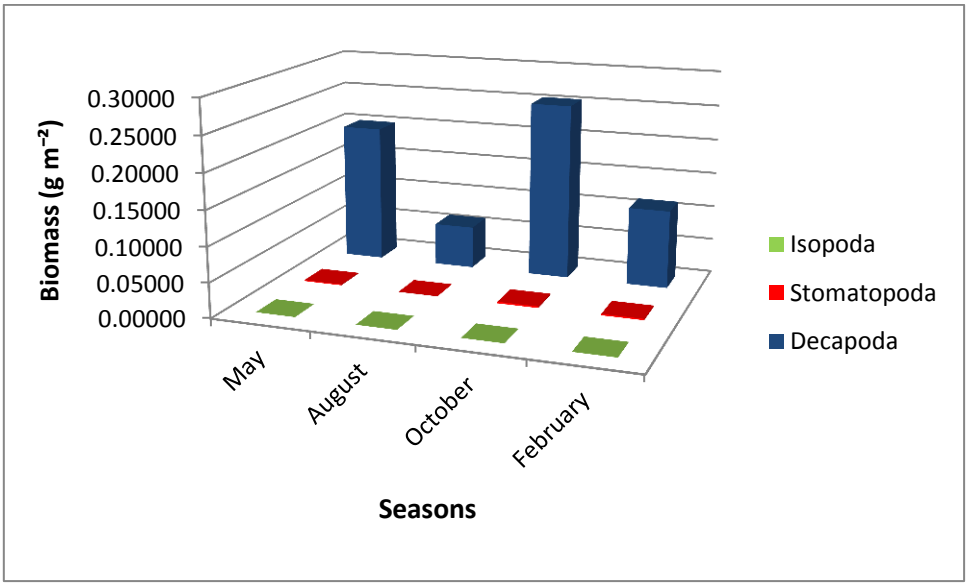


Figure 25 Biomass of each order of Crustacea in the seasons.

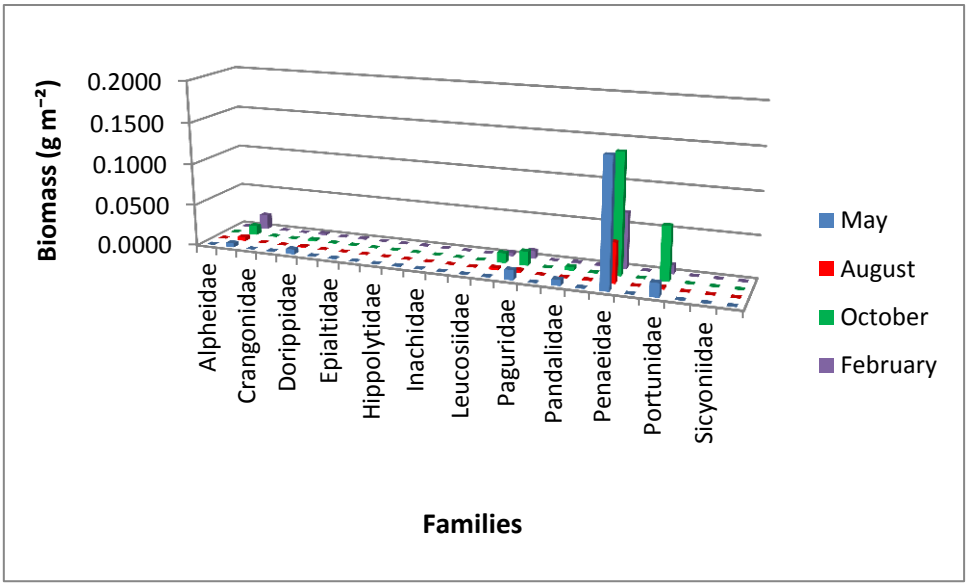


Figure 26 Biomass of each family of Decapoda in the seasons.

3.3 Faunistic characters

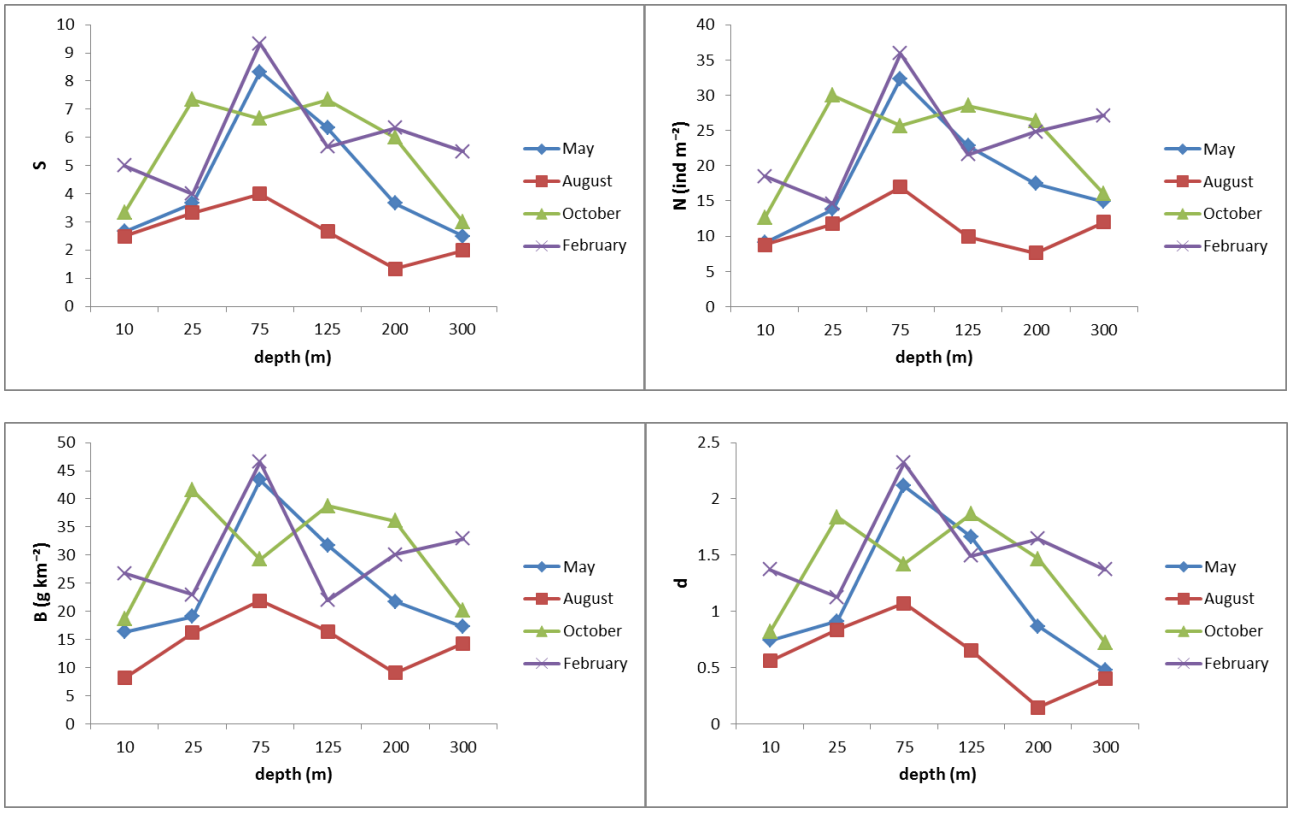
Three-way ANOVA revealed that there was a significant effect of depth and season on diversity of benthic crustaceans ($P < 0.05$; Table 5). Each index was found within the same range between transects, with exception in August whose indices were lower than those of the other seasons. Spatio-temporal changes in the number of crustacean species (S), abundance (N), biomass (B), species richness (D), evenness (J'), and Shannon-Wiener diversity (H'), expressed as the average of three transects, were revealed (Figure 27). Diversity indexes calculated for each season showed differences according to depths and values of October and February were higher than those of May and August. All the indices increased with depth from shallow tp deep waters. In general they reached the peaks at 75 m in May, August and February and at 25 m in October and fluctuated in the deeper waters (Fig 27).

The highest mean S values were observed at 75 m depth stations for most of the seasons. At this depth, mean S values of February (9.33), May (8.33), and August (4.00) were higher than those registered at the other depths. On the contrary, in October were observed highest S values at 25 m and 125 m depth (both S = 7.33). The shallowest (10 m depth) and deepest stations (300 m depth) were the poorest in each season.

Abundance was highly variable among depths, varying from 8.74 in shallow stations (10 m depth) to 35.93 in the stations at intermediate depth (75 m), and then decreasing again in the deeper stations (200 m) to 7.61. Evenness (J') was significantly low at most of depths in May and August, reaching a maximum of 0.33 in August at 200 m and of 0.45 in May at 300 m. This pattern was due to the finding of only one species at some stations of these depths.

Table 5 P-values from 3-way analysis of variance for number of species (S), abundance (N), biomass (B) and diversity indexes (species richness, D; evenness, J'; and Shannon-Wiener diversity index, H'). Bold numbers show P< 0.05.

Source	d.f	S	N	B	D	J'	H'
Season	3	0.054	0.416	0.054	**0.045**	0.117	0.073
Transect	2	0.335	0.135	0.335	0.259	0.289	0.103
Depth	5	**0.024**	**0.016**	**0.024**	**0.015**	0.606	**0.011**
Season*Transect	6	0.448	0.781	0.448	0.505	0.644	0.665
Season*Depth	15	0.46	0.769	0.46	0.493	0.51	0.593
Transect*Depth	9	0.415	0.481	0.415	0.422	0.193	0.28



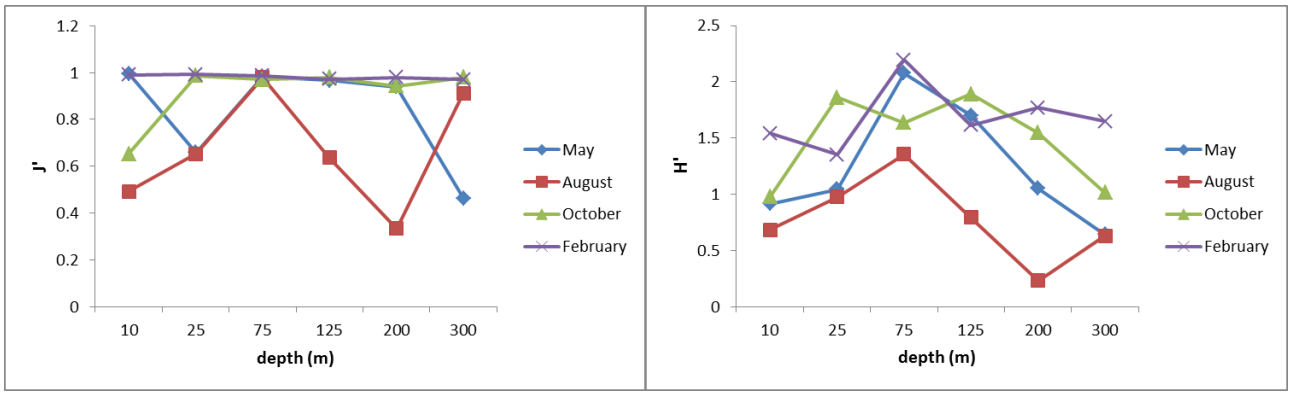


Figure 27 Spatio-temporal (depth and months) changes of crustacean faunistic parameters on the Antalya Gulf for number of crustacean species (S), abundance (N), biomass (B), species richness (D), evenness (J'), and Shannon-Wiener diversity (H') indexes. Each point represents the values obtained from averaging values of each parameters across three transect at each depth.

3.4 Analysis of crustacean community

3.4.1 Abundance

Three-way PERMANOVA on abundance data showed that there were significant differences in the crustacean distribution among all 3 factors (Season, Depth and Transect) and in the interactions Season with Depth and Transect with Depth (P< 0.05; Table 6).

Table 6 Nonparametric (permutation-based) MANOVA over abundance data. Depth and Transect are fixed, Season is random. Bold numbers show P < 0.05

Source	df	SS	MS	Pseudo-F	P(perm)	perms	P(MC)
Season	3	16277	5425.7	2.8477	**0.001**	999	0.001
Transect	2	13196	6598	3.4921	**0.005**	999	0.002
Depth	4	65097	16274	6.0465	**0.001**	997	0.001
SexTr	6	11330	1888.3	0.99112	0.507	999	0.482
SexDe	12	32588	2715.6	1.4253	**0.015**	998	0.023
TrxDe	8	24824	3103	1.6286	**0.006**	998	0.011
Residual	20	38105	1905.3				
Total	55	2.05E+05					

The *Cluster hierarchical analysis* based on Bray Curtis index revelaed differences in crustacean assemblages in relation to bottom depths (Figure 28).

With analysis of nMDS plot (0.14 stress) this situation appears more clear, with the sample-point of deepest group well aggregated , and more far to point of the others groups of site of shallow waters.

The nMDS ordination showed seasonal fluctuations among depths and this pattern was more evident on shallow stations (10-25 m depth). On the contrary, deep-water stations (200 m depth) appeared less heterogenous. The intermediate waters resulted dispersed but less then shallow waters.

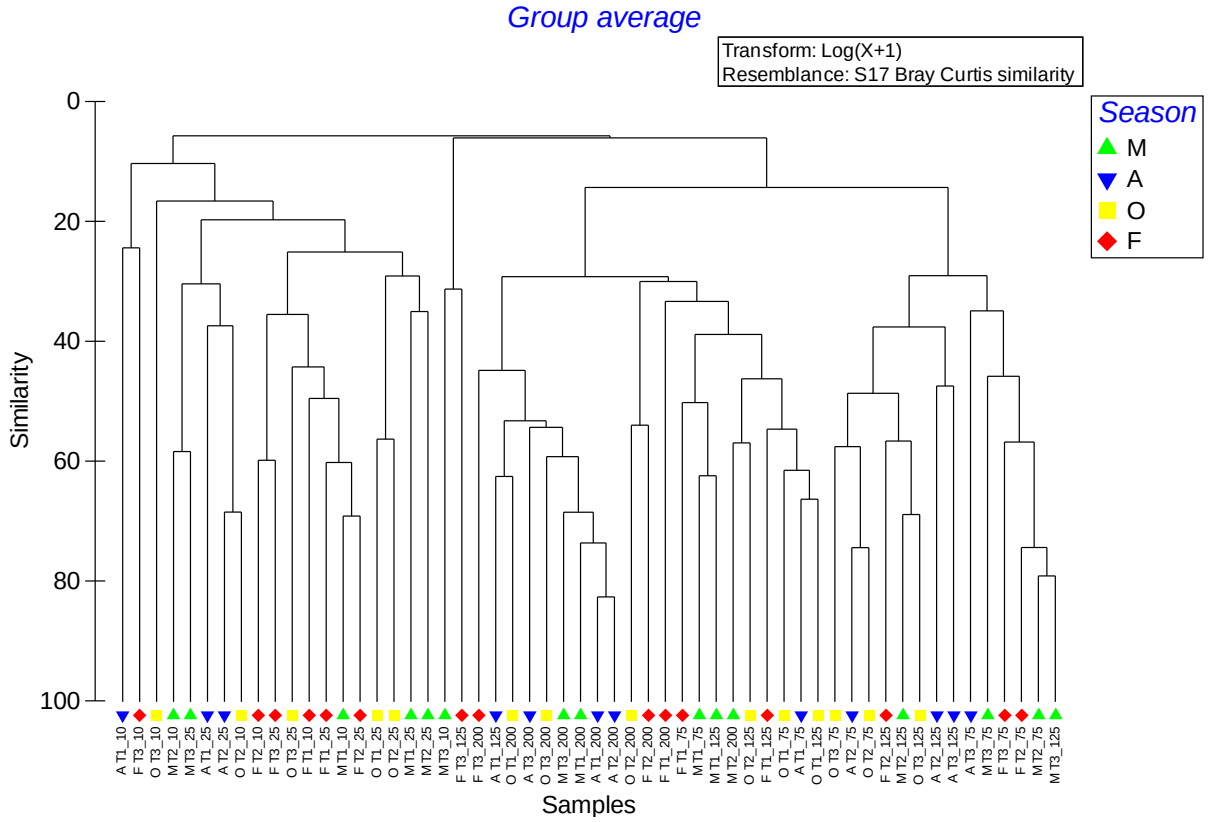


Figure 28 Cluster hierarchical analysis of abundance data obtained from Bray-Curtis matrix.

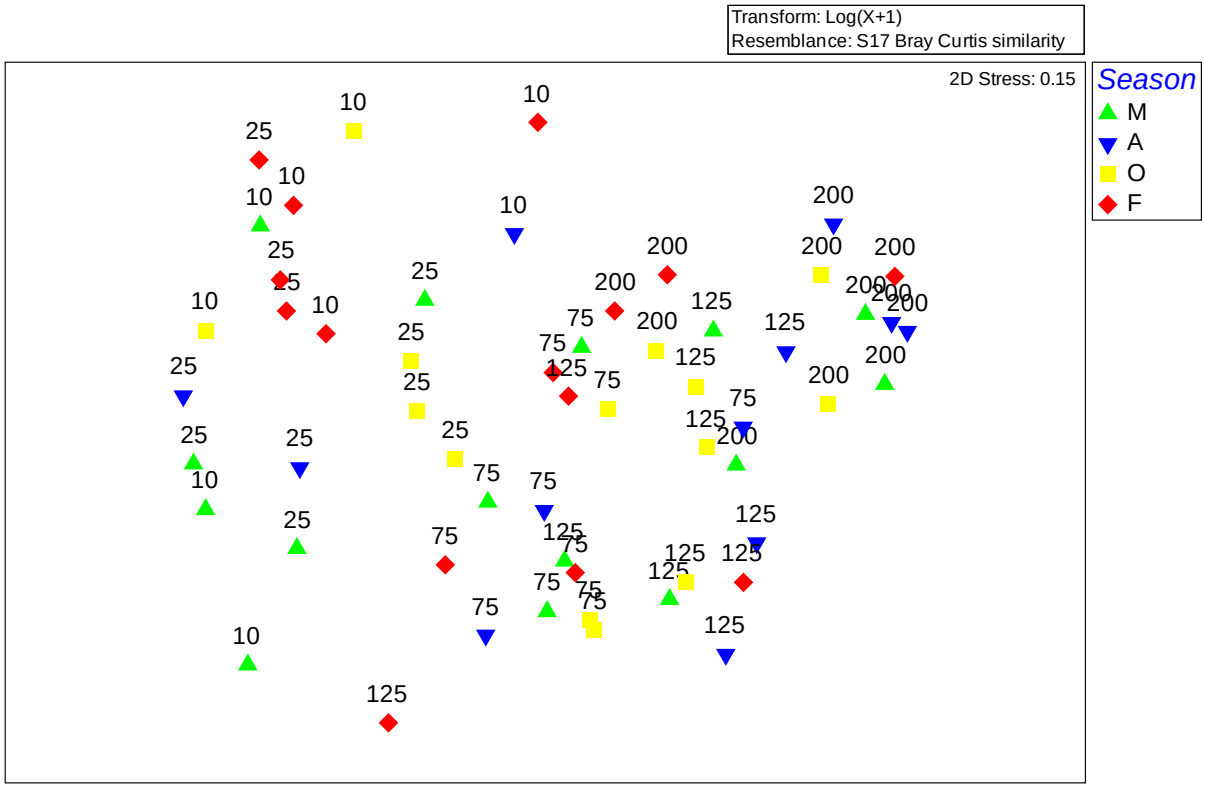


Figure 29 nMDS performed on log-transformed abundance values of the crustacean taxa.

To investigate the species that mainly contribute to characterize each assemblage a SIMPER analysis was performed. The results of SIMPER analysis within each group were not reported, but contributors species of each group were identified from the comparison of mean abundance between groups. Seasonal groups displayed very low mean similarities of species composition (May = 15.31; August = 15.96; October = 20.69; February = 14.05). The most contributing species for each season were: *Charybdis longicollis* (May, Av.Sim = 2.85), *Parapenaeus longirostris* (August, Av.Sim = 8.21), *Pagurus prideaux* (October, Av.Sim = 9.41) and *Marsupenaeus japonicus* (February, Av.Sim= 2.85).

The SIMPER results of seasonal groups highlighted the high average dissimilarity between groups of August and February (Av.diss = 88.05; Table 7). This dissimilarity is probalby due to the high abundance of *Parapenaeus longirostris* in August and to diminuition of average abundace of *Marsupenaeus japonicus* and *Charybdis longicollis* from February to August.

Table 7 Dissimilarity result table of SIMPER analysis between a pairwise of crustacean communities among season. In bold are discriminator species among the groups; in underlined are contributors species within group; δ is the dissimilarity.

Species	Av.Abund	Av.Abund	δ	δ/SD	Contrib %	Cum. %
Aver.dissimilarity	**Group**	**Group**				
86.74	**Group M**	**Group A**				
Parapenaeus longirostris	1.83	**2.53**	11.24	0.81	12.95	12.95
Pagarus prideaux	2.01	1.8	9.02	0.83	10.4	23.35
Charybdis longicollis	**1.46**	0.69	6.42	0.72	7.4	30.75
Medorippe lanata	1.34	0.89	4.91	0.83	5.66	36.41
Pisa armata	1.2	0.26	4.34	0.68	5.01	41.41
Derilambrus angulifrons	0.71	0.87	4.06	0.7	4.69	46.1
83.92	**Group M**	**Group O**				
Pagarus prideaux	2.01	**4.24**	9.2	1.27	10.96	10.96
Parapenaeus longirostris	1.83	2.96	7.99	0.86	9.52	20.49
Charybdis longicollis	1.46	1.32	4.61	0.88	5.49	25.98
Farfantepenaeus aztecus	0.2	**1.44**	4.03	0.69	4.8	30.78
Pisa armata	1.2	0.67	3.77	0.73	4.49	35.26
Medorippe lanata	1.34	0.72	3.27	0.8	3.89	39.16
82.1	**Group A**	**Group O**				
Pagarus prideaux	1.8	**4.24**	9.9	1.39	12.06	12.06
Parapenaeus longirostris	2.53	2.96	9.78	0.96	11.91	23.97
Farfantepenaeus aztecus	0.24	**1.44**	4.63	0.73	5.64	29.6
Charybdis longicollis	0.69	1.32	4.19	0.81	5.1	34.7
Derilambrus angulifrons	0.87	0.96	3.87	0.77	4.71	39.42
Thalamita poissonii	0.9	0.5	3.54	0.5	4.31	43.73
84.36	**Group M**	**Group F**				
Parapenaeus longirostris	1.83	1.6	6.41	0.77	7.6	7.6
Pagarus prideaux	2.01	1.66	6.39	0.76	7.57	15.16
Marsupenaeus japonicus	0.74	**1.58**	5.29	0.81	6.27	21.44
Charybdis longicollis	1.46	1.56	5.27	0.86	6.25	27.68
Pisa armata	1.2	1.17	4.41	0.83	5.22	32.91
Medorippe lanata	1.34	1.32	4.04	0.89	4.79	37.7
88.05	**Group A**	**Group F**				
Parapenaeus longirostris	**2.53**	1.6	9.24	0.87	10.49	10.49
Pagarus prideaux	1.8	1.66	7.4	0.81	8.4	18.9
Marsupenaeus japonicus	0.37	**1.58**	5.87	0.82	6.67	25.57
Charybdis longicollis	0.69	**1.56**	4.83	0.82	5.49	31.06
Medorippe lanata	0.89	1.32	4.29	0.84	4.87	35.93
Penaeus hathor	0	**1.22**	4.18	0.67	4.75	40.68
84.49	**Group O**	**Group F**				
Pagarus prideaux	**4.24**	1.66	8.38	1.33	9.91	9.91
Parapenaeus longirostris	**2.96**	1.6	6.97	0.9	8.25	18.17

Marsupenaeus japonicus	1.04	1.58	4.56	0.89	5.39	23.56
Charybdis longicollis	1.32	1.56	4.04	0.93	4.78	28.34
Penaeus hathor	0.94	1.22	3.71	0.83	4.39	32.74
Farfantepenaeus aztecus	**1.44**	0.43	3.68	0.75	4.35	37.09

The SIMPER analysis showed very low average similarities within each transect, because the very different crustacean assemblages observed at different depth (T1: Av.sim. = 22.25 ; T2: Av.sim. = 17.82; T3: Av.sim. = 11.21). Average dissimilarities among transects were high (Table 8) with significance differences betwen T1 and T3 (Av.diss. = 86.37), T2 and T3 (Av.diss. = 85.39) and between T1 and T2 (Av.diss. = 84.79). *Parapenaeus longirostris* and *Medorippe lanata* contributed significantly to T1, while *Pisa armata* nd *Pagurus prideaux* toT3

Table 8 Dissimilarity result table of SIMPER analysis between a pairwise of crustacean communities between transect. In bold are discriminator species among the groups; in underlined are contributors species within group; δ is the dissimilarity.

Species	**Av.Abund**	**Av.Abund**	**δ**	**δ/SD**	**Contrib %**	**Cum. %**
Aver.dissimilarity	**Group**	**Group**				
84.79	**Group 1**	**Group 2**				
Parapenaeus longirostris	**3.64**	1.42	9.36	0.94	11.04	11.04
Pagarus prideaux	1.66	**3.8**	8.95	1.07	10.56	21.6
Charybdis longicollis	1.77	1.16	5.03	0.94	5.93	27.53
Medorippe lanata	**2.17**	0.5	4.9	0.98	5.77	33.31
Marsupenaeus japonicus	1.23	0.73	4.12	0.69	4.86	38.17
Derilambrus angulifrons	0.38	1.3	3.41	0.75	4.03	42.2
Thalamita poissonii	0.41	0.92	3.21	0.51	3.79	45.98
86.37	**Group 1**	**Group 3**				
Parapenaeus longirostris	**3.64**	1.51	10.42	0.95	12.07	12.07
Pagarus prideaux	1.66	1.79	5.87	0.91	6.79	18.86
Medorippe lanata	**2.17**	0.55	5.27	0.99	6.11	24.97
Charybdis longicollis	1.77	0.91	5.09	0.8	5.89	30.86
Marsupenaeus japonicus	1.23	0.92	4.56	0.73	5.28	36.14
Pisa armata	0	**1.46**	3.59	0.73	4.16	40.3
Farfantepenaeus aztecus	**1.15**	0.2	3.14	0.63	3.63	43.94
85.39	**Group 2**	**Group 3**				
Pagarus prideaux	**3.8**	1.79	10.16	1.03	11.9	11.9
Parapenaeus longirostris	1.42	1.51	6.84	0.66	8.01	19.91
Pisa armata	1.15	1.46	5.23	0.86	6.13	26.04
Charybdis longicollis	1.16	0.91	4.76	0.73	5.58	31.62
Derilambrus angulifrons	1.3	0.98	4.36	0.83	5.1	36.73
Marsupenaeus japonicus	0.73	0.92	3.51	0.66	4.11	40.84
Penaeus hathor	0.57	0.7	2.94	0.59	3.45	44.28

In the analysis of depth groups (Table 9) was found very interesting results that explain the crustacean community structure of the study area.

The group with the highest average similarity was represented by the stations at 200 m depth (av.sim. = 39.33), being that showing the low number of species. The species characterizing depth groups were *Penaeus hathor* (10 m depth, av.sim. = 4.73), *Charybdis longicollis* (25 m depth, av.sim. = 16.44), *Pagarus prideaux* (75 m depth, av.sim. = 11.92; 125 m depth, av.sim. = 12.83) and *Parapenaeus longirostris* (200 m depth, av.sim = 34.70).

Among depths, the highest average dissimilarities were observed between 10 and 200 m depth (av.diss= 97.96), and between 25 and 200 m depths (av.diss = 97.43). These dissimilarities were due to an inversion of dominance of the mainly contributing species. Species that were very abundant in the shallow waters such as *Charybdis longicollis* and *Marsupenaeus japonicus* were not found in the deep stations. On the other hand, species that were typical of deep zones such as *Parapenaeus longirostris* and *Plesionika spp* were lacking in shallow waters.

Table 9 Dissimilarity result table of SIMPER analysis between a pairwise of crustacean communities between depths. In bold are discriminator species among the groups; in underlined are contributors species within group; δ is the dissimilarity.

Species	**Av.Abund**	**Av.Abund**	**δ**	**δ/SD**	**Contrib %**	**Cum.%**
Aver.dissimilarity	**Group**	**Group**				
80.94	**Group 10**	**Group 25**				
Charybdis longicollis	0.72	**3.8**	10.54	1.47	13.02	13.02
Marsupenaeus japonicus	1.89	2.38	7.9	1.14	9.76	22.78
Penaeus hathor	2.08	1.49	6.62	1.1	8.18	30.96
Thalamita poissonii	**1.85**	0.8	6.6	0.77	8.15	39.11
Erugosquilla massavensis	0.93	1.76	5.58	0.91	6.9	46.01
93.03	**Group 10**	**Group 75**				
Pagarus prideaux	0	**4.77**	12.07	1.46	12.97	12.97
Pisa armata	0.73	**2.64**	6.46	1.14	6.94	19.91
Derilambrus angulifrons	0.34	**2.2**	5.94	1.08	6.39	26.3
Medorippe lanata	0	**2.22**	5.35	1.03	5.75	32.05
Marsupenaeus japonicus	1.89	0.65	4.82	0.89	5.18	37.23
97.3	**Group 10**	**Group 125**				
Pagarus prideaux	0	**4.2**	13.13	1.23	13.49	13.49
Parapenaeus longirostris	0	**2.24**	6.04	0.7	6.2	19.7

Penaeus hathor	**2.08**	0	5.49	1.03	5.64	25.34
Marsupenaeus japonicus	**1.89**	0	5.27	0.79	5.41	30.75
Thalamita poissonii	**1.85**	0	5.01	0.66	5.15	35.9
97.96	**Group 10**	**Group 200**				
Parapenaeus longirostris	0	**6.15**	21.96	1.98	22.42	22.42
Penaeus hathor	**2.08**	0	5.86	1.02	5.99	28.41
Marsupenaeus japonicus	1.89	0.24	5.72	0.8	5.84	34.25
Thalamita poissonii	**1.85**	0	5.36	0.65	5.47	39.72
Portunus pelagicus	**1.13**	0	4.83	0.63	4.93	44.65
87.75	**Group 25**	**Group 75**				
Pagarus prideaux	0.93	**4.77**	10.39	1.36	11.84	11.84
Charybdis longicollis	**3.8**	1.45	6.8	1.29	7.75	19.59
Pisa armata	0.33	2.64	6.23	1.09	7.09	26.69
Derilambrus angulifrons	0	2.2	5.74	1.08	6.54	33.22
Marsupenaeus japonicus	**2.38**	0.65	5.08	1.03	5.79	39.01
93.97	**Group 25**	**Group 125**				
Pagarus prideaux	0.93	4.2	11.09	1.13	11.8	11.8
Charybdis longicollis	**3.8**	0.29	10.24	1.52	10.9	22.7
Marsupenaeus japonicus	**2.38**	0	5.93	0.97	6.31	29.01
Parapenaeus longirostris	0	**2.24**	5.6	0.7	5.96	34.97
Medorippe lanata	0.35	1.82	4.53	0.92	4.82	39.79
97.43	**Group 25**	**Group 200**				
Parapenaeus longirostris	0	**6.15**	20.01	1.9	20.54	20.54
Charybdis longicollis	**3.8**	0.24	11.08	1.51	11.37	31.9
Marsupenaeus japonicus	**2.38**	0.24	6.33	0.96	6.5	38.4
Pagarus prideaux	0.93	1.51	4.49	0.79	4.61	43.01
Erugosquilla massavensis	1.76	0	4.42	0.82	4.53	47.55
72.47	**Group 75**	**Group 125**				
Pagarus prideaux	4.77	4.2	7.34	1.14	10.13	10.13
Parapenaeus longirostris	1.89	2.24	5.9	0.89	8.14	18.27
Pisa armata	**2.64**	0.52	5.81	1.09	8.02	26.29
Derilambrus angulifrons	2.2	1.08	4.88	1.02	6.73	33.02
Medorippe lanata	2.22	1.82	4.73	1.07	6.53	39.55
84.79	**Group 75**	**Group 200**				
Parapenaeus longirostris	1.89	**6.15**	11.57	1.43	13.64	13.64
Pagarus prideaux	**4.77**	1.51	10.49	1.3	12.37	26.01
Pisa armata	**2.64**	0	6.4	1.07	7.55	33.56
Derilambrus angulifrons	2.2	0.59	5.56	1.03	6.55	40.11
Medorippe lanata	2.22	0.68	5.04	1.01	5.94	46.06
79.33	**Group 125**	**Group 200**				
Parapenaeus longirostris	2.24	**6.15**	13.85	1.14	17.46	17.46
Pagarus prideaux	**4.2**	1.51	11.62	1.16	14.65	32.11
Medorippe lanata	**1.82**	0.68	4.74	0.93	5.98	38.09
Calappa granulata	1.4	1.1	4.35	0.94	5.48	43.57
Pagurus excavatus	0.59	1.14	3.56	0.73	4.48	48.06

3.4.2 Biomass

Three-way PERMANOVA on biomass data showed the same results of abundance data. Significant differences in the crustacean assemblages were detected among all three factors (Season, Depth and Transect) and in the interactions Season X Depth and Transect X Depth ($P< 0.05$; Table 10)

Table 10 Nonparametric (permutation-based) MANOVA over biomass data. Depth and Transect are fixed, Season is random. Bold numbers show $P < 0.05$

Source	df	SS	MS	Pseudo-F	P(perm)	perms	P(MC)
Season	3	15354	5118.2	2.7091	**0.001**	999	0.001
Transect	2	12239	6119.6	3.4373	**0.003**	999	0.001
Depth	4	65201	16300	6.0077	**0.001**	999	0.001
SexTr	6	10638	1773	0.93847	0.622	998	0.587
SexDe	12	32862	2738.5	1.4495	**0.015**	999	0.022
TrxDe	8	25145	3143.2	1.6637	**0.004**	998	0.007
Residual	20	37785	1889.3				
Total	55	2.04E+05					

The *Cluster hierarchical analysis* and nMDS ordination were as well performed over biomass data. The *Cluster hierarchical analysis* showed most gradual changes of crustacean assemblages related to bottom depth (Fig 30). Like as the abundance nMDS plot, also in the biomass nMDS plot three main groups were detected related to bottom depth (Figure 31), with gradual changes from to very shallow waters (10m-25m depth), through the intermediate (75m-125m depth) to deep waters (200m depth). Seasonal changes among stations were more relevant at the shallow depths (10-25m) than at deep waters (125-200m) where the crustacean communities appeared more homogeneous.

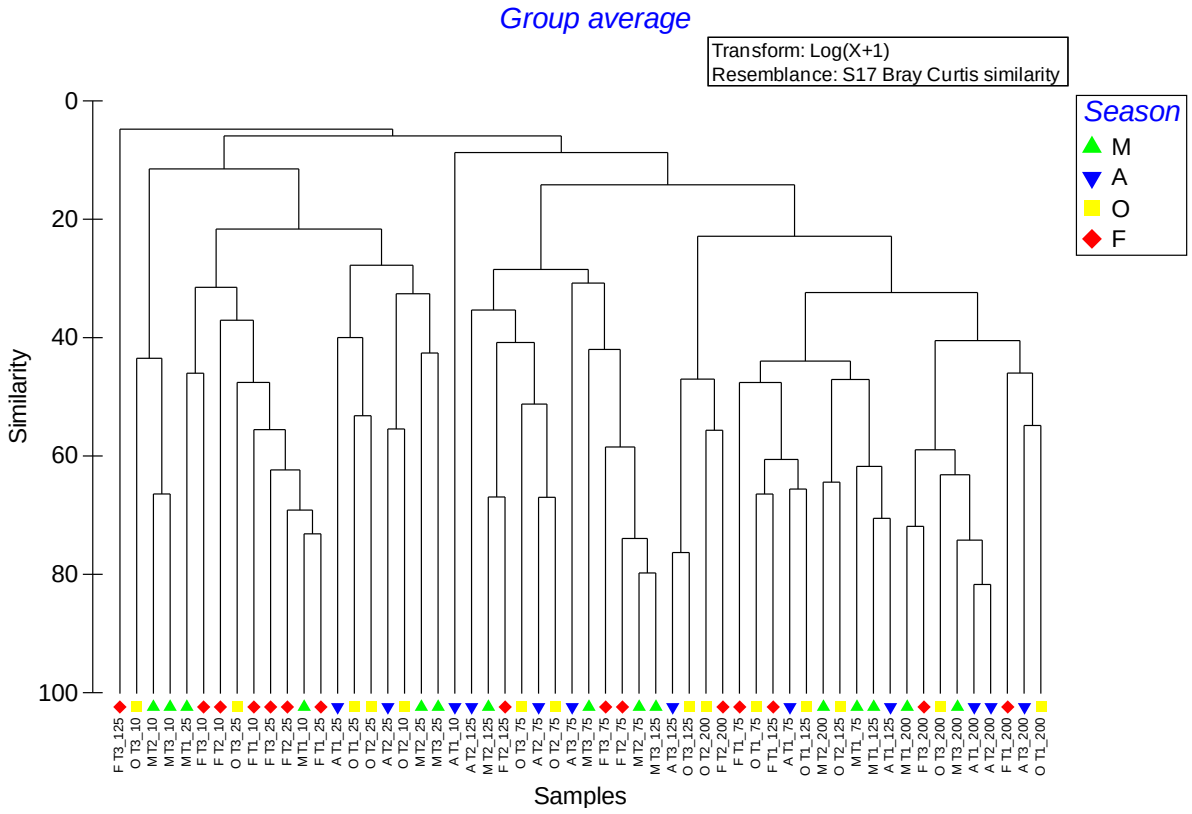


Figure 30 Cluster hierarchical analysis over abundance data obtained from Bray-Curtis matrix.

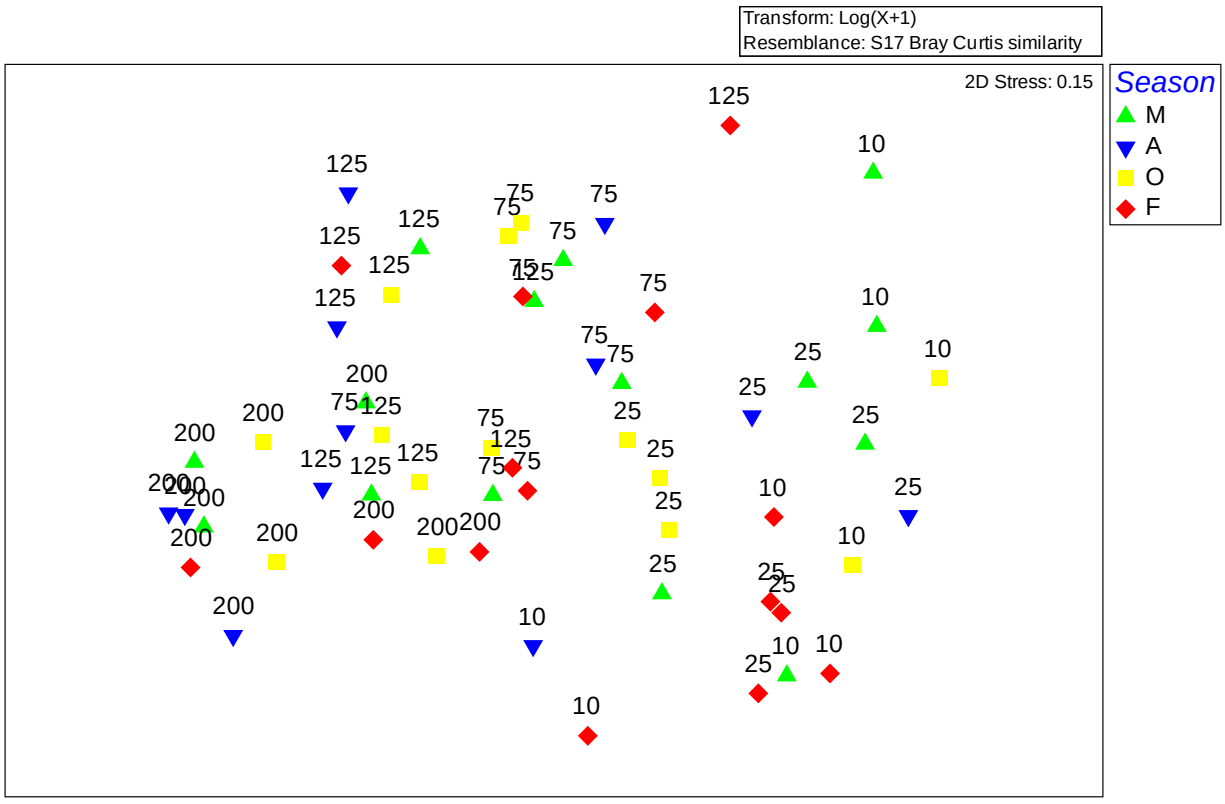


Figure 31 nMDS performed on log-transformed abundance values of the crustacean taxa.

3.4.3 Relationships between biological data and environmental parameters

The analysis to investigate the correlation between biotic and abiotic variables was performed troughout BIO-ENV analysis. It was done a comparison of dissimiliarity ranks obtained from transformed matrices, to test how the environmnetal parameters explained the sample variation based on community structure.

Table 11 Best correlation result between biotic matrix and environmental matrix resulting from BIO-ENV analysis.

No.Variable	Correlation	Selection
7	0.545	Depth; BottomType; NBOx; SST; NBT; SSS; SSD
5	0.544	Depth; BottomType, NBT; SSS; SSD
4	0.542	Depth; NBT; SSS, SSD
3	0.540	Depth; SST; SSD
2	0.537	Depth; SST
1	0.522	Depth

BIO-ENV analysis showed that the best explaination of community variation is given by the combination of 7 variables (Table 11, Spearman correlation = 0.545) and the variable which has the highest Spearman correlation index is the bottom depth (Spearman correlation = 0.522). The environmental parameters providing the best explanation of the variation of the benthic crustacean communities were Depth, Bottom Type, oxygen content of near bottom waters, temperature of sea surface and near bottom waters, and sea surface density and salinity.

To evaluate how these environmental variable were changed and explained the spatio-temporal variation of crustacean communities a Canonical Correspondence Analysis (CCA) analysis was performed. Species composition were oriented principally in association with Depth and Bottom type, as previously resulted from BIO-ENV analysis (Fig. 32). With a comulative percentage variance of 20.4 % for species data, and 39.3 % for the species-environment relationship on the first two axes (Table 12).

Here, the environmental parameters are represented by the arrows, and each arrow shows the marginal effect of the particular environmental variable upon the sample stations in the ordination diagram. The distance of sample stations represented in the diagram approximates the dissimilarity of their crustacean composition. Shallow and deep stations are located on the opposite corners of CCA ordination while intermediate depth stations are centered in the ordination.

Table 12 Summary of results of CCA performed on log-transformed value of the crustacean and environmental variables

Axes	1	2	3	4
Eigenvalues	0.678	0.444	0.360	0.258
Species-environment correlations	0.974	0.914	0.875	0.891
Cumulative percentage variance of species data	7.7	12.7	16.8	19.7
Cumulative percentage variance of species-environment relation	14.8	24.5	32.4	38.1

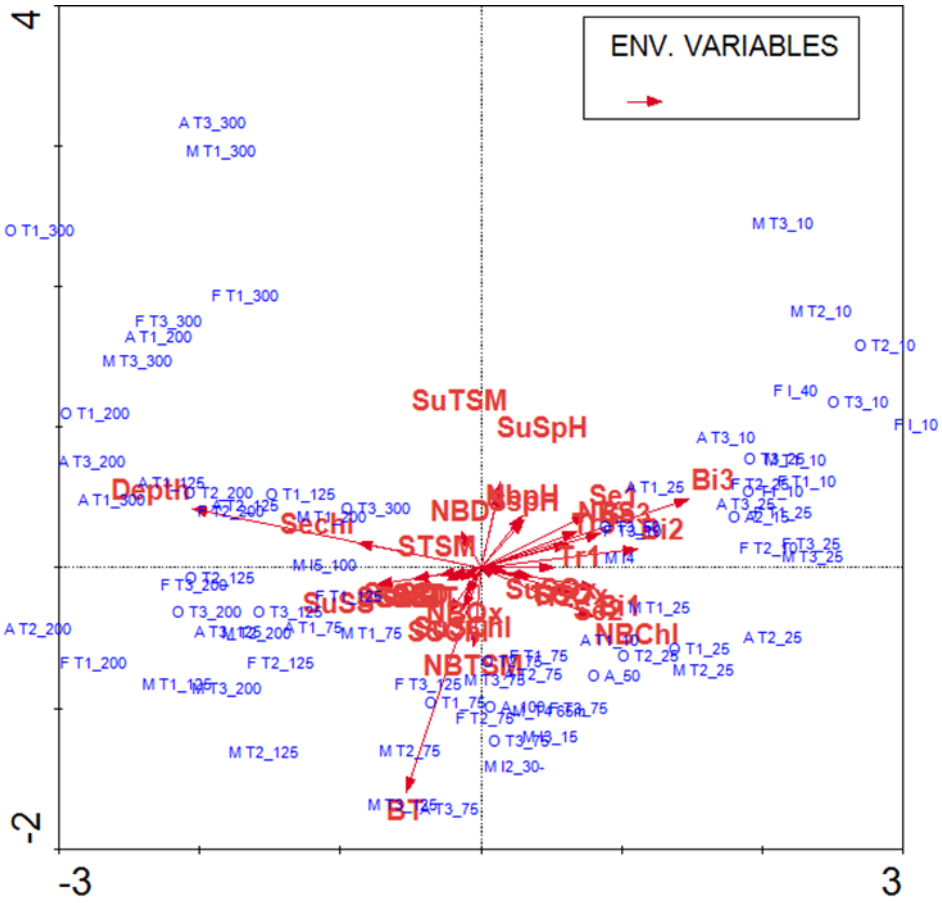


Figure 32 Biplot of CCA performed on log-transformed values of the crustacean and environmental variables (arrows) on sample stations.

The figure 33 is a scatterplot based on previous CCA ordination (Fig. 32) representing the distribution of species. The distance between species points in the ordination approximates the dissimilarity of distribution of relative biomass of those species across the samples. The points in proximity to each other correspond to species often occurring together. The distribution of species follows the increasing of the depth like the previous ordination, within the positive quadrant the shallow species and with the increasing of depth the species characterizing the intermediate waters and lastly in the most deepest water the presence of typical deep species.

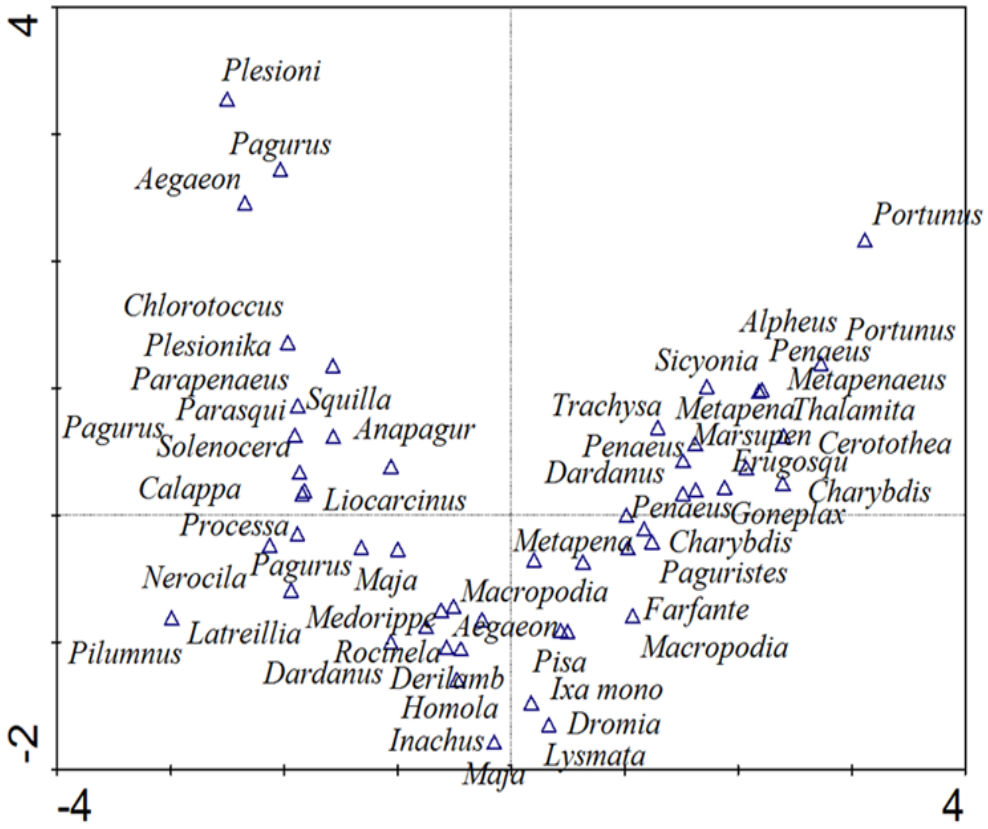


Figure 33 Scatter plot if CCA performed on log-transformed value of the crustacean samples.

3.5 Spatio-temporal distribution of *Parapenaeus longirostris*

Parapenaeus longirostris was one of the most common crustaceans of the present study. The species was observed in all sampling months and it was distributed on deep-water stations (> 75 m depth). Its highest abundance and biomass were observed at 200 m and 300 m depth. Its biomass was higher in May and October than in February and August (Fig 34) reaching the peak value of 12771.5 g/Km² at 300 m depth in May.

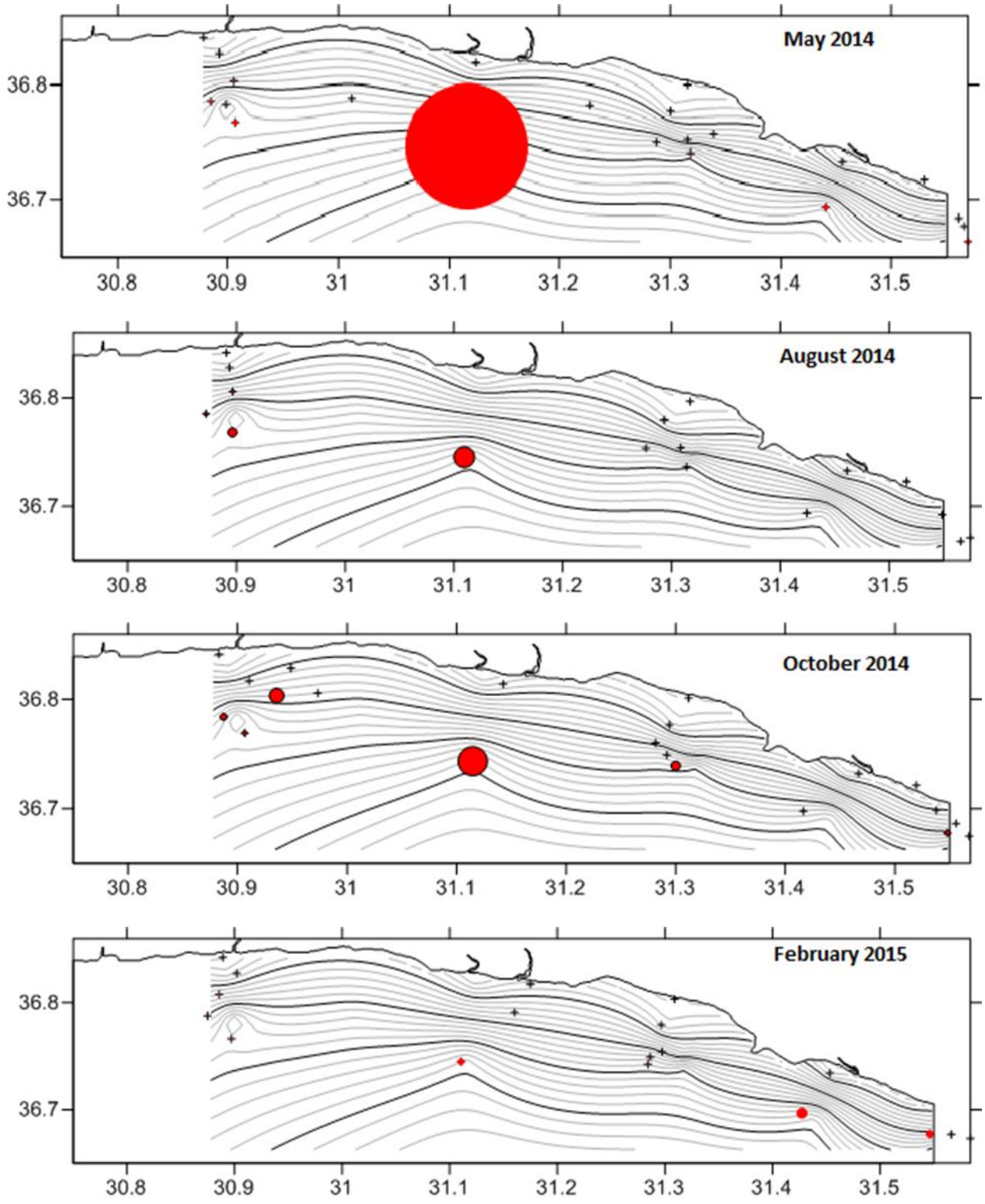


Figure 34 Spatio-temporal distribution of *Parapenaeus longirostris* based on biomass data. The largest circle corresponds to the maximum weight of species (12771.5446 g/Km²).

In order to have a better representation of its depth distribution, a nMDS plot based on abundance transformed data of this species was performed (Fig. 35), where the bubbles indicate the different abundance values in the corresponding sampling stations (max value 21902.01 ind/Km²)

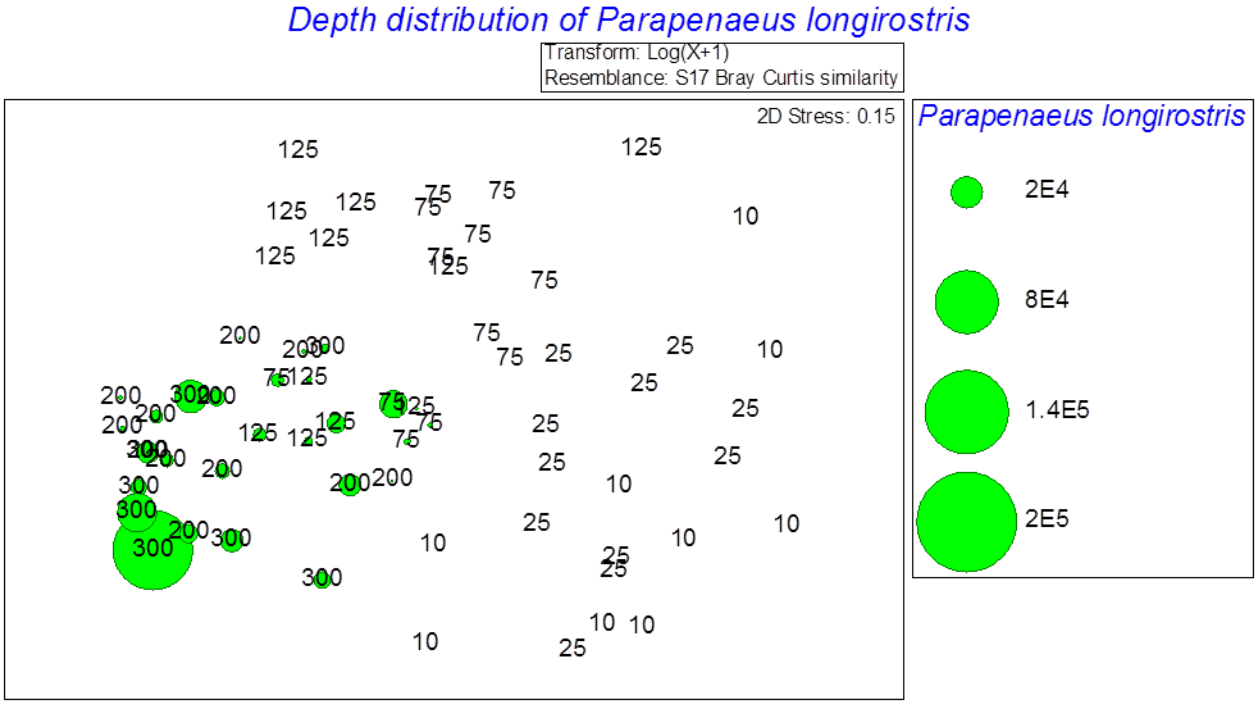


Figure 35 nMDS plot of depth distribution of abundance of *Parapenaeus longirostris* .

The SIMPER analysis revealed that the main difference among depth groups were related to the abundance of *Parapenaeus longirostris* (Table 13), being the main contributing species at 200 and 300 m depth. *Parapenaeus longirostris* showed the most Sim/SD in 300 m depth, (Sim/SD= 3.29).

The deep-water rose shrimp was the most discriminating species between shallow and deep groups (Table 13). the average dissimilarity for *Parapenaeus longirostris* was very high between 10 and 300 m depth stations (δ= 23.45) and the percentage contribution of this dissimilarity between the two groups was 24.16. Similarly the average dissimilarity was very high between 25 and 300 m depth stations (δ=21.94). This was because at 10-25 m depth this species was not found. Indeed *Parapenaeus longirostris* was also a discriminating species between 75 m and 300 m depth groups, with a contribution to dissimilarity of 15.79 and an high average dissimilarity (δ=13.71).

Table 13 Dissimilarity result table of SIMPER analyses between a pairwise of crustacean communities in seasons groups. In bold are discriminator species among the groups; in underlined are contributors species within group; δ is the dissimilarity.

Average dissimilarity	Av.Abund	Av.Abund	δ	δ /SD	Contrib%
Groups 10 & 75	Group 10	Group 75			
92.56	0	2.54	4.23	0.64	4.57
Groups 25 & 75	Group 25	Group 75			
86.82	0	2.54	4	0.64	4.61
Groups 10 & 125	Group 10	Group 125			
97.39	0	3.01	5.56	0.77	5.71
Groups 25 & 125	Group 25	Group 125			
94.03	0	3.01	5.24	0.75	5.57
Groups 75 & 125	Group 75	Group 125			
74.03	2.54	3.01	6	0.9	8.1
Groups 10 & 200	Group 10	Group 200			
97.94	0	**7.41**	19.22	2.14	19.63
Groups 25 & 200	Group 25	Group 200			
97.03	0	**7.41**	17.99	1.82	18.54
Groups 75 & 200	Group 75	Group 200			
84.7	2.54	**7.41**	11.12	1.35	13.13
Groups 125 & 200	Group 125	Group 200			
78.49	3.01	7.41	13.49	1.01	17.18
Groups 10 & 300	Group 10	Group 300			
97.04	0	**9.27**	23.45	3.16	24.16
Groups 25 & 300	Group 25	Group 300			
97.12	0	**9.27**	21.94	2.48	22.59
Groups 75 & 300	Group 75	Group 300			
86.88	2.54	**9.27**	13.71	1.53	15.79
Groups 125 & 300	Group 125	Group 300			
84.16	3.01	**9.27**	16.4	1.19	19.49
Groups 200 & 300	Group 200	Group 300			
58.79	7.41	9.27	5.3	1.21	9.02

The sex ratio of *Parapenaeus longirostris* was different than the expected 1:1. There was a significant difference in the proportion of the number of female and male (χ^2=1786.7 ; $p<0.05$) with a predominance of females (65.11% F; 34.89% M). The ANOVA of morphometric parameters revealed that there were significant differences for factor Depth in the LogCL, LogCW and Weight, and for factor Zone in the LogCL and LogCW ($P< 0.05$;Table 14). The main differentiated group for these morphometric parameter was that sampled at 300 m depth, with specimens of larger size. The abundance of the species was significantly different in the interaction between Season and Depth.

Table 14 P-values from 3-way analysis of variance for Carapace length, carapace width, total length (data transformed), and weight. Bold numbers show P< 0.05.

Source	d.f	Abundance	LogCL	LogCW	LogTL	Weight
Season	3	0.135	0.838	0.53	0.791	0.864
Zone	1	0.197	**0.05**	**0.04**	0.051	0.059
Depth	3	0.071	**0.029**	**0.026**	0.059	**0.02**
Season*Zone	3	0.063	0.299	0.509	0.50	0.511
Season*Depth	6	**0.033**	0.799	0.646	0.672	0.81
Zone*Depth	3	0.364	0.445	0.539	0.489	0.496

The best morphological trend of growth was given by the relationship Carapace Length – Weight. The CL frequency distribution of females and males was different, showing different growth rates between sexes. The carapace length-total weight (CL-W) relationship of female and male were determined (Fig 36), respectively as $W= 0.0005CL^{2.6916}$ (R^2=0.9712) for female and $W=0.0004CL^{2.7525}$ (R^2=0.9312) for male. As shown in the figure 36, the size-weight relationships of both sexes revealed a slight negative allometry in growth, giving a "b" value less than 3. Such allometry was more pronounced in females than in male (2.6916 for female and 2.7525 for male). The carapace length of females ranged between 12.30 mm to 44.80 with a mean of 27.86mm and that of males ranged from 11.80 to 39.50 mm with a mean of 21.25mm.

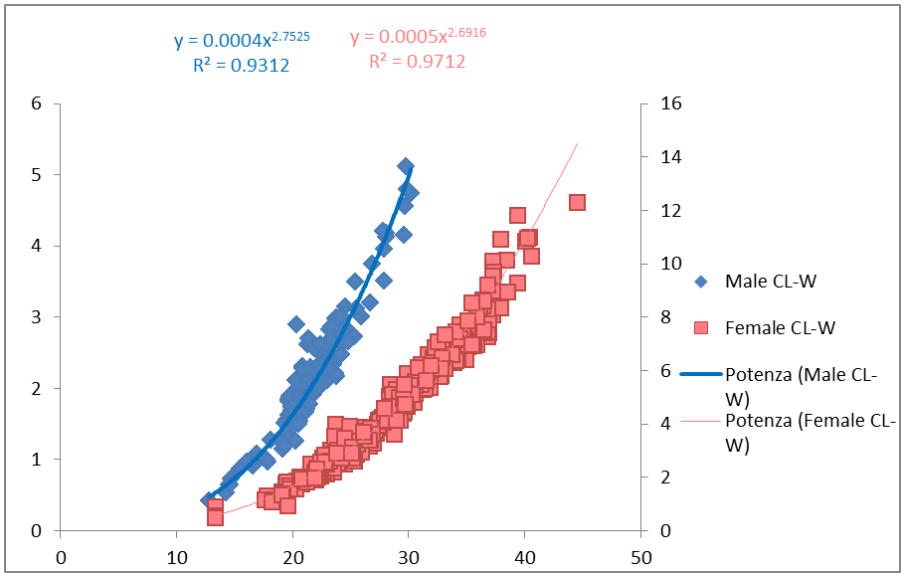


Figure 36 Carapace length-Weight relationship of female and of male of *Parapenaeus longirostris*

Throughout the Bhattacharya's method the modal groups (cohorts) were identified from the length frequency data analysis for both sexes of *Parapenaeus longirostris*. As shown in table 15, up to eight cohorts were detected for both males and females. These eight groups displayed different length frequency distribution in the female and male groups. For example the first cohort considered for female has CL mean length of 19.45 mm and for male the first cohorts is relatively more tiny with CL mean length of 16.46. The group with higher number of individual is the second cohort (for female CL mean length of 22.93mm and for male CL mean length of 20.68mm). The results of Bhattacharya's analysis are reported in figure 37 for female and in figure 38 for male with corresponding eight curves for each sex.

Table 15 Modal groups from the length frequency analysis (Carapace length in mm) of *Parapenaeus longirostris* using Bhattacharya's method (CL: mean of carapace length, SD: standard deviation, Population: the number of individuals, SI: separation index).

	Female				Male			
Group	CL	SD	Population	SI	CL	SD	Population	SI
1	19.45	0.870	1104	-	16.46	0.540	386	-
2	22.93	0.920	3167	3.890	20.68	1.190	3203	3.880
3	26.11	0.560	901	4.300	23.16	1.070	2180	2.190
4	29.17	0.990	2955	3.950	26.17	0.730	1014	3.340
5	32.40	0.650	1088	3.940	28.48	1.480	2025	2.090
6	34.32	0.500	1331	3.340	34.42	1.070	1374	4.660
7	36.06	0.700	896	2.900	37.00	0.670	636	2.970
8	39.50	0.480	194	5.830	39.80	0.820	189	3.760

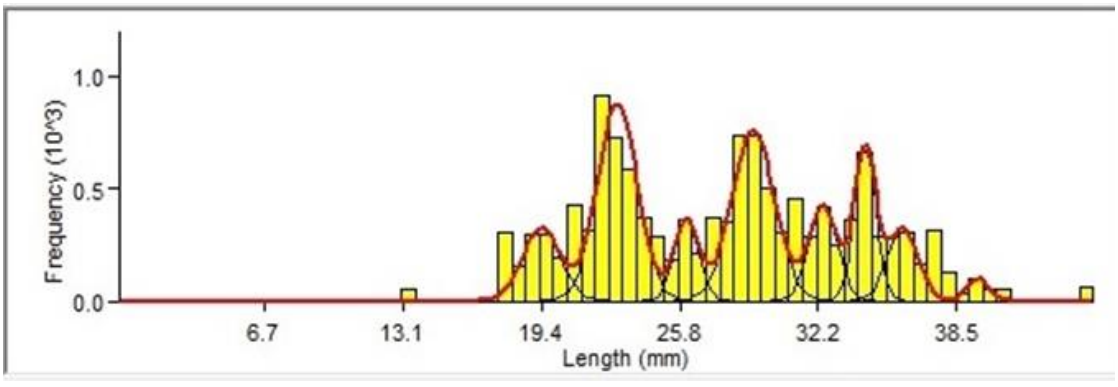


Figure 37 Observed Carapace length frequency distribution of Female of *Parapenaeus longirostris,* the curves shows eight cohorts.

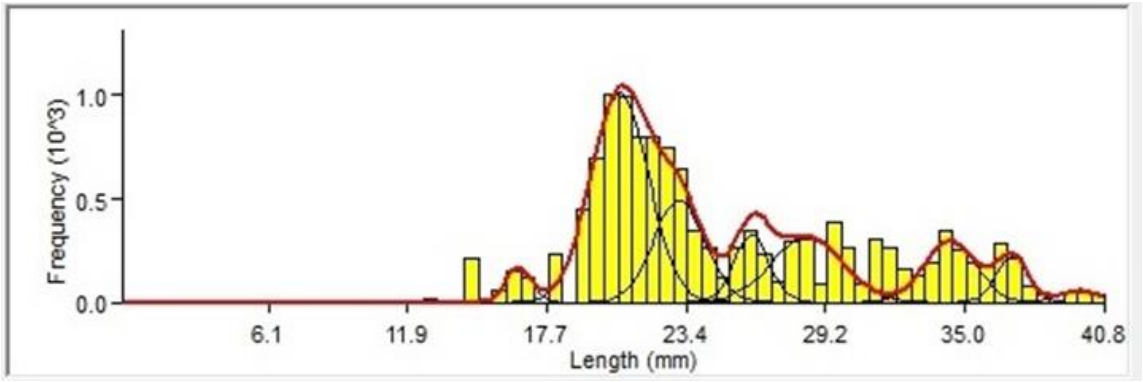


Figure 38 Observed Carapace length frequency distribution of Male of *Parapenaeus longirostris*, the curves shows eight cohorts.

Lastly, a paired sample t-test was performed between mean length of females and males of these cohorts to show any significant differences. Differences in the mean length (cohorts) classes were statistically significant between male and female ($t= 2.610$; $p< 0.05$). This result confirm that the length - weight relationship of *Parapenaeus longirostris* changes over the sex, being each cohort significance between the sexes, and the females are always larger than males for each cohorts.

4. Discussion

4.1 Community structure

Throughout the year of study in the Antalya gulf 58 species of crustacean were found, and 3 orders were observed belonging to the crustacean class. The average number of species ranges from 2 to 11 for each sample station, and there was a relevant seasonal effect. Indeed the average density of benthic crustacean showed a seasonal changes, increasing from warmer seasons to colder seasons. This result contrasts with other studies which found high densities of crustaceans in warmer season (Harriague *et al,* 2006), but according to others (Ergev, 2002).

Some crustacean species were identified as common in the area. The most common crustacean species were *Pagurus prideaux* (Leach, 1815) and *Parapenaeus longirostris* (Lucas, 1846) followed by *Charybdis longicollis* (Leene, 1938), and *Marsupenaeus japonicus* (Spence Bate, 1888). Most of the species were considered rare being recorded only in a few stations throughout the year.

A few species contributed high amount to the total biomass. These species were the invasive swimming crab *Charybdis longicollis*, the hermit crab *Pagurus prideaux* and the deep-water rose shrimp *Parapenaeus longirostris*. The high presence of erythrean crab *Charybdis longicollis* is an example of established Lessepsian species in the Levantine Sea through the Suez Canal. This portunid crab was firstly recorded in the Mediterranean Sea in 1959 off the Turkish coast (Holthuis, 1961) and later occurred from Egypt to Cyprus (Lewinsohn and Holthuis, 1986). This alien crab represents as much as 70% of the benthic biomass on muddy-sand bottoms at 25 - 60 m depth, off the Israeli coast (Galil, 1986; Galil and Lützen, 1995), and according to that, in the present study, it was revealed that 64% of benthic crustacean biomass is composed of this invader in the shallow and intermediate waters (10 - 75 m).

The decapods represent the most dominant crustacean group in the study area, with an high abundance, confirming the findings of Sardà *et al*, (1994) and Tyler and Zibrowius (1992). These studies hypothesized that the oligotrophic nature of Mediterranean waters is one of the environmental factors contributing to the high abundance of decapods instead of other oceans, in which other megafaunal invertebrates predominate.

Comparing the composition and distribution of species and the faunistic characters of megistobenthic crustaceans in the Antalya Gulf, it was observed that communities were structured principally by depth and bottom type. An increasing of many indices, like biomass, species richness and number of species, was detected from shallow stations (10-25m) to intermediate ones (75m). On the contrary, a clear decrease of the same indices was observed in the deeper stations (200 - 300m). In general, sampling stations showed similar faunistic characters of benthic crustacean communities among the three transects. These univariate analyses, give a general indication of number of crustacean species, diversity. However, the information regarding differences of crustacean composition in the stations are lost with these analysis. For this reason is necessary to use a multivariate approach, considering the abundance and biomass to discriminate the composition of benthic crustacean among the stations.

In this sense, from a multivariate point of view, the present study confirms the validity of the crustacean community as a bioindicator of environmental variables to differentiate the shallow waters from deep waters. The multivariate analyses, conducted on the abundance data, point out major differences between depths and between seasons. Cluster analysis and ordination of the abundance and biomass data revealed three main groups of crustacean assemblages: shallow waters (10-25m), intermediate waters (75m) and deep-water (125-200m). These results were highlighted from correlation analysis between environmental parameters and crustacean communities (throughout the BIO-ENV and CCA analysis).

These analysis revealed how the crustacean community is structured in the Antalya Gulf, following different dynamics. These were mainly due to the physical characteristics of water like sea surface and near bottom waters temperature, sea surface density and salinity, substrate bottom type, and especially depth. This tight linkage between the community and bottom depth, is confirmed by Clarke *et al*, (1993), who suggested that benthic community structure would change with an increase of water depth. Moreover, a considerable effect of seasonal variation was detected, which consequentially influenced the response of benthic communities associated to the sampling sites. These significant differences are quite conspicuous in the crustacean assemblages of shallow waters, while deep-water crustacean assemblages appeared steady throughout the year. These changes in the communities of shallow waters are correlated with the changing of sea surface water temperature, which has a mean of 22.5 ± 1.9 ^{0}C through the year, and reaches the peak value of 27.5 ^{0}C in August and in February decreases until 18.8 ^{0}C.

The analysis of correlation between benthic crustacean assemblages and environmental variables pointed out that the substrate type is a significant factor leading the crustacean distribution. Rocks with seagrasses and muddy sand bottom were well diversified with higher values of faunistic characters and especially high number of species. These results suggest the important role of sediment type in determining the spatial changes of crustacean assemblages. Previous studies demonstrated that the substrate type has a direct influence on benthic assemblages (Beaman and Harris, 2007; Gray, 1981; Harriague *et al*, 2007).

The depth drives the direct gradient effect on crustacean distribution pattern. This was evidenced by the CCA scatterplot with the variation of distribution of species. In the shallow waters were found *Portunus pelagicus* and *Portunus hastatus*, and commercial shrimps such as *Penaeus hathor*, *Penaeus semiculcatus* and *Marsupenaeus japonicus*. As the depth increase as the presence of *Pisa armata* and *Medorippe lanata* is more frequent in the intermediate waters. In the deeper waters we registered the presence of few species of aphotic zone like *Plesionika spp*, *Aegaeon catachtractus* and *Parapenaeus longirostris*

The SIMPER analysis showed that some species play an important role in structuring the crustacean community especially in the deeper zone. *Parapenaeus longirostris* , *Plesionika edwardsii* (Brandt, 1851) and *Plesionika heterocarpus* (A. Costa, 1871) were found only in stations > 125 m depth and they were the dominant species in the aphotic zones. These results, especially regarding the high presence of commercial Pandalidae *Plesionika* spp in the aphotic zone, were largely confirmed by previous literature among all Mediterranean Sea (Mura, 1987; Colloca, 2002; Abelló *et al.,* 1988).

The species mainly structuring the seasonal crustacean assemblages were *Charybdis longicollis* in May, *Parapenaeus longirostris* in August, *Pagurus prideaux* in October and *Marsupenaeus japonicus* in February. The results of seasonal comparisons highlighted an high dissimilarity between August and February. This dissimilarity is probably due to the high abundance of penaeids in February such as *Marsupenaeus japonicus* and *Farfantepeaneus aztecus*, whose abundance can be explained by the reproductive biological traits of Peneaids (Sobrino *et al.,* 2005).

Eighteen species out of the 58 megistobenthic crustacean species found in this study were non native species and they amount to a total of 31%. Among these alien species, the knight rock shrimp *Sicyonia lancifer* (Olivier, 1811), belonging to Sicyonidae family, was recorded for the first time in Mediterranean Sea,. Moreover it was reported the presence of the

brachyuran crab *Latreillia elegans* (Roux, 1830) and of the stomatopoda *Parasquilla ferussaci* (Roux, 1828) for the first time in Levantine Sea. The knight rock shrimp is an Indo-Pacific species widely distributed in Japan - Kagoshima, Vietnam, Indonesia - Arafura Sea, Malaysia, Penang, Sri Lanka - Gulf of Manaar, Maldives, Mozambique (De Freitas A.J., 1984). The species *Latreillia elegans* and *Parasquilla ferussaci* were previously reported in the western part of the Mediterranean Sea. The first species was reported up to the Aegean Sea in Rhode Island (Balkıs H and Asurluoğlu L., 2002), while the second one was reported in the Eastern Atlantic Ocean (Froglia & Manning, 1989) and in almost all Mediterranean Sea, from the Gulf of Cadiz (Colmenero *et al*, 2009) to Sicily (Pipitone and Tumbiolo, 1993), and up to the Aegean Sea (Özcan *et al*, 2008). The area of Antalya was already reported as one of the Levantine areas with highest number of crustacean alien species (Bakir *et al*, 2014). The detected presence of *Sicyonia lancifer* in this area, reported as the first occurrence in Mediterranean Sea, reinforces the common invasion pattern of Lessepsian species that are going to be established in the Levantine Sea and further progressively spread westward and northward in the Mediterranean to Ionian and Aegean Sea (Katsanevakis *et al*, 2013).

In conclusion, the crustacean diversity appeared to be moderately good in the Antalya Gulf, according to the previous findings obtained on the benthic communities in the eastern Mediterranean. Studies carried out in these waters, for example, revealed a total of 153 infaunal crustacean species in northern Cilician Shelf (Mutlu, 2015), 22 crustaceans were found in the Antalya Gulf (Bingel *et al*. 1995). In the Iskenderun Bay, Gücü *et al*. (2001) found 30 crustacean species and 19 crustacean species were found in Gulbahce Bay by Cinar *et al* (1998).

4.2 Parapenaeus longirostris

In the deep-water rose shrimp population of the Antalya Gulf females predominated (65.11%). D'Onghia *et al.* (1998) showed that the sex ratio is influenced by the depth; females seem to be more abundant at depth < 200 m, while the presence of females and males similar at 200-400 m depth. This trend changes after 400 m where males become predominant. Indeed the results presented in this thesis are in agreement with this study, since that the haul with maximum depth was at 300 m depth.

The species showed a sexual dimorphism with females larger than males for each cohort. The max carapace length was 44.80 mm in females and 39.50 mm in males. This could suggest that males grow more slowly than to females, as were largely reported in literature (Sobrino *et al.,* 2005; Fortibuoni *et al.,*, 2010). The size-weight relationships of both sexes revealed a slight negative allometry in growth, a bit more pronounced in females compared to male, according to Sobrino (1998).

The statistical analysis of morphometric parameters and biomass revealed significant differences between fishing and not fishing zone, with larger sizes in the no fishing zone, probably because in the fishing zone the organisms are of smaller size for the fishing activities removing the specimens of bigger sizes. The population dynamics of the deep-water rose shrimp in the Antalya Gulf showed significant differences in depth, especially passing from photic to aphotic zone, and among interaction between season with depth. Differences were detected also in morphometric parameters related to bathymetry, having found larger specimens in the deeper waters.These results could be explained by ecology and migratory movements.
Previous studies (Bayhan *et al*., 2005; Sobrino *et al.*, 2005) in Mediterranean waters, showed that mature females of *Parapenaeus longirostris* are present during all year, so the spawning occurs continually throughout the year, but the most intensive spawning takes place in October-November. After the period of spawning, the deep-water rose shrimps pass through the pelagic larval stages typical of Decapoda. At the end, the post-larva, that are similar to adults, reach the bottom of the continental shelf in spring and started benthic phase of its life cycle. New generations recruite at the border of the shelf (generally 100-180 m depth), grow in biomass and size, migrate from the middle shelf towards the continental slope, in deeper waters (Ardizzone *et al*., 1990; Heldt, J.H.,1938; Ribeiro-Caschalho and Arrobas, 1987; Tom *et al*, 1988).

5. Conclusions

In conclusion, the results of the present thesis highlight the variation of the benthic crustacean communities in the Antalya Gulf along with an entire year and explore the complexity of communities and the relation of their structure to environmental factors. This study demonstrates that depth and substrate have a major role in shaping the crustacean assemblages of the Antalya Gulf.

How just said, the present thesis has been conceived to investigate the crustacean species diversity, and how crustacean marine assemblages are related to the variation of environmental variables throughout the year, in the Gulf of Antalya in the eastern part of Mediterranean Sea. The study was carried out within the framework of a wider project aiming at investigate the semi-demersal and demersal fish assemblages of the Antalya Gulf, including the study of the megistobenthic fauna. There, this study is only a initial contribution to the building up of a general overview of the benthic assemblages of the Antalya Gulf. The data and results here reported, and the concurrent environmental variables, will be material for further integrative work. It is well known that the variability of benthic assemblages reflects the whole functioning of the marine ecosystems and these are the bases of the trophic chain. So, the realization of a well-structured monitoring, widely distributed in time and space, is crucial and necessary for a superior understanding of spatio-temporal, qualitative and quantitative distribution of benthic organisms.

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