ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Copepods distribution patterns in an upwelling system off Northwest Africa (Southern Moroccan Atlantic coast)

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Manuscript Info

Manuscript History:

Received: 21 April 2015
Final Accepted: 22 May 2015
Published Online: June 2015

Key words:

Copepods, Diversity, Spatial distribution, Northwest Africa, Southern Atlantic Moroccan coast, Upwelling.

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Abstract

In order to assess copepods distribution and diversity within southern Atlantic Moroccan coast, two surveys were carried out between Cape Blanc (21°N) and Cape Boujdor (26°N) during two seasons (fall and summer).
Copepods were clearly predominant (more than 90%) in both seasons. During fall copepods composition were dominated by the species *Oncea venusta* (44%), *Clausocalanus arcuicornus* (18%) while in summer *Acartia clausi* (18%) and *Clausocalanus arcuicornus* (15%) were the most abundant. According to distribution maps of densities and structural indexes of the population, obvious differences were identified between southern and northern parts of Dakhla (24°N). Indeed, the southern area remained the richest and most diversified as clusters analyses of copepods densities corroborated these results, thus two principal groups were distinctly identified. Similarly, distribution maps of hydrological parameters have depicted two distinguish areas separated by Dakhla region (24°N). These results were confirmed by Mann-Whitney U test performed on northern and southern densities and environmental parameters.

INTRODUCTION

Moroccan Atlantic Coast is well known for its important and diversified production which is mainly due to the upwelling activity in this zone that induces phytoplankton and zooplankton proliferation (Thiriot, 1978; Barber and Smith, 1981; Coste and Minas, 1982; Binet, 1988; Cushing, 1989; Roy, 1991; Makaoui et al., 2005).
Several studies have been conducted concerning zooplankton and copepods description within the Moroccan coastal system (Furnestin, 1976; Belfequih, 1980; Chiahou et al., 1998; Chiahou, 1990; Chiahou, 1997; Chiahou and Ramdani 1997; Youssara et al., 2004; Salah et al., 2012). Moreover, other investigations were specifically focused on the area between 21°N and 26°N (Somoue, 2004; Somoue et al., 2005; Zizah et al., 2012) or concerned only the upwelling system of Cape Blanc (Binet, 1973; Vives, 1974).
In addition, many researches have been carried out on copepods in other regions in the world affected by the phenomenon of upwelling (Boyd et al., 1980; Hidalgo and Escribano, 2007; Hidalgo et al., 2012) as this component account for 75% of total abundance of zooplankton in all the world's oceans (Raymont, 1983).
Actually, the investigated area situated between Cape Blanc (21°N) and Boujdor (26°N) is considered as one of the most productive zones of Morocco since it is submitted to a particularly intense and permanent upwelling (Minas et al., 1982; Binet, 1991; Makaoui et al., 2005; Cropper et al., 2014).

The aim of the current study is to attempt to describe how copepods are distributed in this region during two sampling campaigns (fall 2011 and summer 2012) and define the possible relation existing between copepods population and environmental parameters.

Materials and Methods

Sampling

Between radials 21°N and 26°30'N, sampling was carried out along seven transects during fall 2011 (November) and six transects in summer 2012 (July) abroad the Norwegian ship 'Fridjof Nansen' (Fig 1).

Sampling was made using a plankton-net of 160 microns of mesh. Mesozooplankton was collected in the epipelagic zone up to 200 m for offshore stations. All samples were kept in a formol solution (5%). Temperature and salinity were measured *in situ* using a multiprobe, while chlorophyll'a' concentration was measured in the laboratory by a fluorimetric method (Holms, 1965).

Samples treatment

Mesozooplankton samples were sorted under a dissecting microscope or binocular for enumeration.

Copepods identification was made down to species or genus level using appropriate systematic keys (Rose, 1933; Trégouboff and Rose, 1957; Razouls, 1982 and Razouls et al., 2005). To facilitate identification, a Motoda box was used (Motoda, 1959).

Data analysis

-Densities were calculated as follows: $D = (n*1000) / V$.

Some simple indicators of diversity were calculated:

Species richness: S = the number of species present in each sample.

Diversity index Shannon-Weaver was calculated using the formula: $H' = -\Sigma [(n_i / N) \times \log2 (n_i / N)]$. (Shannon and Wiener, 1949).

Species Evenness was measured using the formula: $J'=H'/\ln(S)$. (Heip, 1974).

-Distribution maps of densities and environmental parameters were performed using the software ODV4 (Ocean Data View 4).

-Using the software PRIMER 5 (Plymouth Routines In Multivariate Ecological Research 5), two types of multivariate analysis were joined in order to identify and aggregate stations having close and similar characteristics: An agglomerative hierarchical classification (Bray and Curtis, 1957) and MDS (Non-Metric Multi-dimensional Scaling). Only dominant species (Zhao and Zhou, 1984) were considered for these analyses (Chen et al, 1994; Xu and Li, 2005; Guo et al, 2011).

-The non-parametric Mann-Whitney U test was applied to compare differences between northern and southern parameters (temperature, salinity, chlorophyll'a', mesozooplakton and copepods densities) with a level of significance of 0,95 (Mann and Whitney, 1947). This test was performed using Data-Mining Coheris Analytics SPAD.

Results:

Mesozooplankton composition and spatial distribution:

19 major taxonomic groups of mesozooplankton were identified. Copepods constituted the highest fraction, representing more than 90% of the total in both seasons.

Cladocera constituted the second dominant group after copepods (6,5% in fall and 2,7% in summer) followed by chaetognatha (3% during fall and 1 % in summer), while the relative abundances of the other groups did not exceed 0.2%. Namely, the group of amphipoda, ostracoda, zoeae, metazoeae, euphausiacea, radiolaria, siphonophora, polychaeta, doliolida, gastropods, acantharia, tintinnida, sponges, appendicularia, foraminifera, and mysidacea (Fig 2).

Mesozooplankton densities maps have displayed high densities in the south part of the area, between Cape Blanc (21°N) and Cintra bay (23°N) during both seasons. A maximum of densities were observed between Cape Blanc (21°N) and Cape Barbas (22°N). (Fig 3, A and B).

Since copepods constituted more than 90% of the total mesozooplankton abundances, thus their geographical distribution have seemed to be similar.

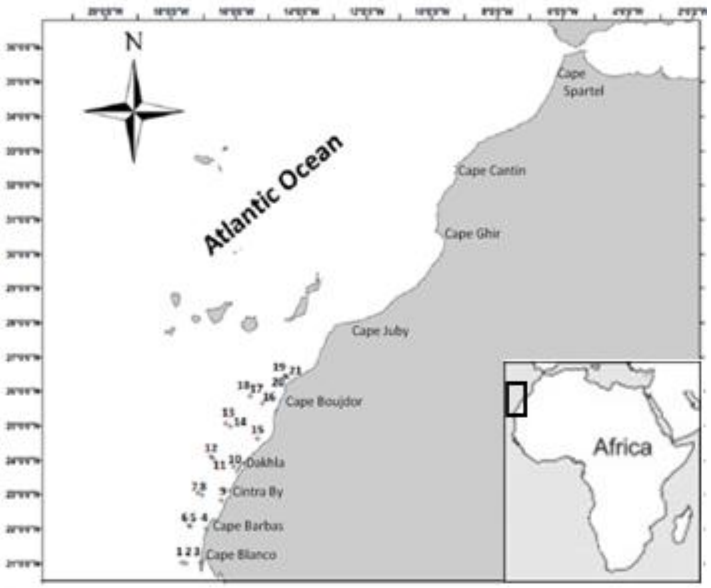

Fig. 1: Geographical location of sampling stations.

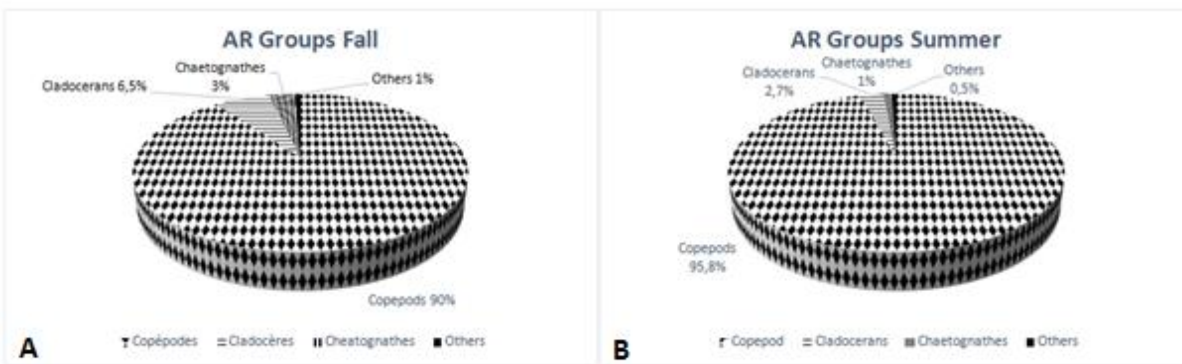

Fig. 2: Relative abundances of mesozooplankton groups (%). A: during fall season, B: during summer.

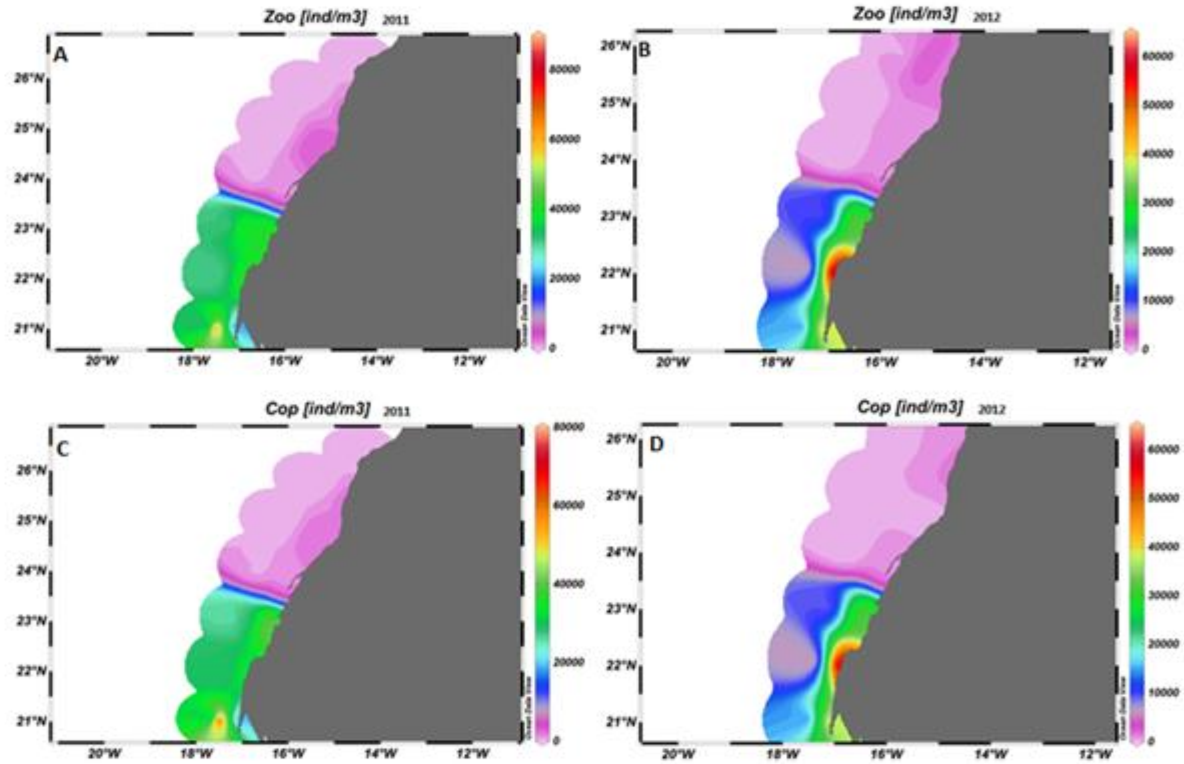

Fig. 3: Distribution maps of mesozooplankton densities (ind/m^3), A: during fall season, B: during summer and copepods densities (ind/m^3), C: during fall season, D: during summer.

Copepods composition and diversity:

A special interest was given to copepods since they constituted the most important group.

In total, 74 copepods species were identified. 67 were recorded in fall against 65 in summer with 65 species in common between both seasons (Tab. 1).

During fall copepods composition was dominated by the species *Oncea venusta* (44%), *Clausocalanus arcuicornus* (18%) while in summer *Acartia clausi* (18%) *and Clausocalanus arcuicornus* (15%) were predominant (Fig 4, A and B).

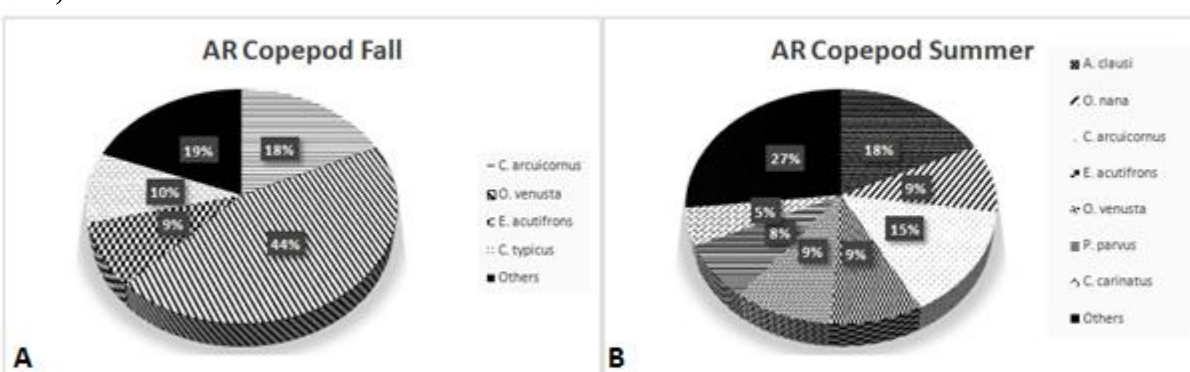

Fig. 4: Relative abundances of identified copepods species (%), A: during fall season, B: during summer.

Structural indexes:

Univariate descriptors measured have shown almost the same results, as one has confirmed the other.

During fall, the highest species richness were observed within the transects 21°N, 24°N, 26°N and 26°30'N, whereas the highest values are observed at Cape Blanc (21°N) and decreased from this region towards 25°N to increase again at Cape Boujdor (26°N) transect in summer (Fig 5, A).

Diversity was considerably important as Shannon-Weaver index ranged from 2 to 3,5 bits/ind (Fig 5, B).

Copepods population were moderately structured to properly structured since Evenness ranged from 0,6 to 0,95 (Fig 5, C).
We have noticed that during both seasons, the highest values of S-W and Evenness indexes were noted at Cape Blanc (21°N), Dakhla (24°N) region and Cape Boujdor (26°N). (Fig 5, B and C).

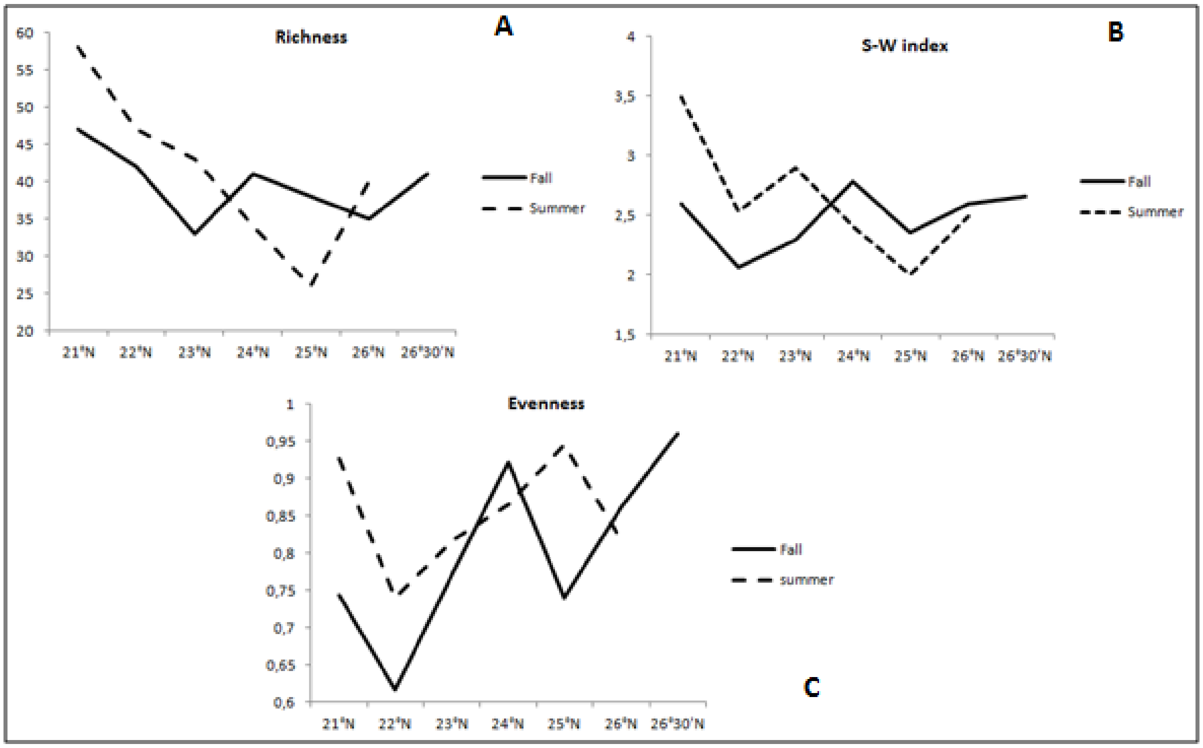

Fig. 5: Copepods richness (A), Shannon-weaver index (B) and Evenness (C) during surveyed periods.

Biogeographical similarity:
According to the cluster analysis obtained in fall, at 40% of similarity, sampled stations were pooled into two main groups according to their species composition.
The first one included six stations which correspond to three transects sampled in the southern of Dakhla region (21°N, 22°N and 23°N). We considered that this group was represented by three aggregations of under-groups: Cape Blanc (21°N) stations (ST 1 and 3), nearshore stations (ST 4 and 9) and offshore stations (ST 5, 6, 7 and 8).
The second principal group contained twelve stations which constituted the rest of sampling stations situated on the north of Dakhla (24°N, 25°N, 26°N and 26°30'N).
Similarly, this second group could be divided into an assemblage of nearshore stations (ST 10, 15 and 16) and another one of offshore stations (ST 11, 13, 14, 17, 18 and 20). 'ST 21' was isolated apart. In fact, this station contained the lowest densities (Fig 6, A).
The same results were obtained during summer. At 37% of similarity, two groups were identified, they separated the three transects of the southern area (21°N, 22°N and 23°N) from the rest of transects (24°N, 25°N, 26°N and 26°30'N).
The first group included all southern stations, except the nearshore station 'ST4' which was singly isolated.
The second group was divided into two main groups that separate nearshore stations (ST9, 10, 15 and 16) from offshore stations (ST 11, 12, 13, 14, 17 and 18). (Fig 7, A).
For both seasons, NMDS representations confirmed the same results.
Actually, stress values were weak enough in fall and summer to judge our results as meaningful. Their respective values were 0,05 and 0,07 (Fig 6, B and 7, B).

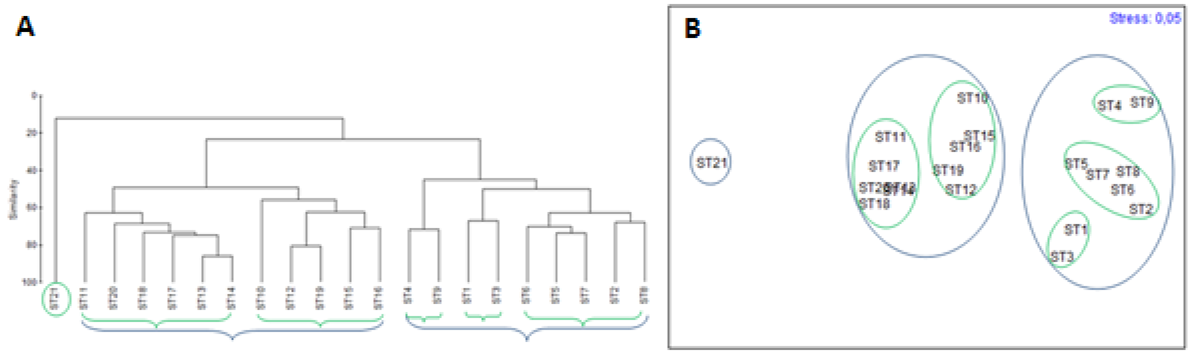

Fig. 6: Cluster dendrogram (A) and plots of the results of NMDS procedure (B) showing relationships between stations according to their species composition in fall season.

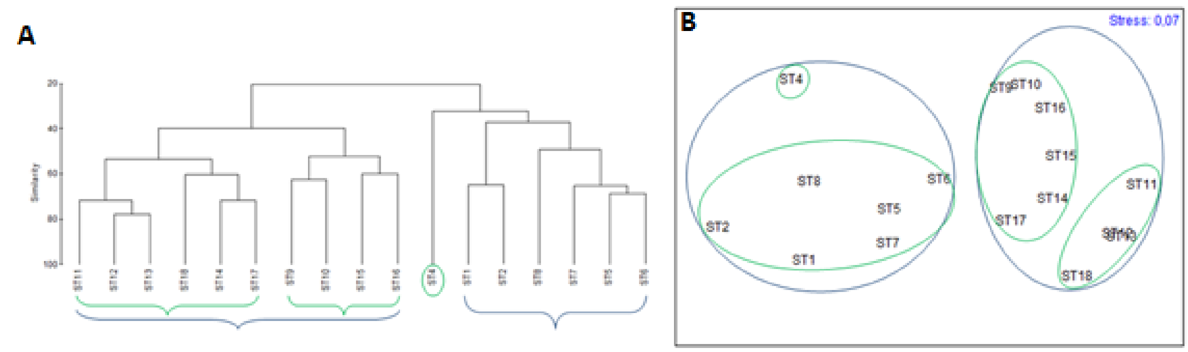

Fig. 7: Cluster dendrogram (A) and plots of the results of NMDS procedure (B) procedure showing relationships between stations according to their species composition in summer.

Environmental parameters:

In order to explain northern and southern differences revealed in our studied area by the previous analysis, environmental parameters (temperature, salinity and chlorophyll'a') were represented on distributional maps (Fig 8).

However, salinity distributions has revealed an obvious difference between northern (21, 22 and 23°N) and southern parts of Dakhla (24, 25, 26°N and 26°30'N) as its values recorded in the south were extremely weaker than those found the north during both seasons (Fig 8, A and B).

Values of temperature were clearly higher in the north region than in the south during fall (Fig 8, C). While in summer, temperature seemed to be almost homogenous all over the studied area (Fig 8, D).

Otherwise, chlorophyll'a' was distributed differently. Actually, high concentrations were recorded above the region of Dakhla (24°N) during fall while the most important concentrations were observed off Cape Blanc (21°N) in summer (Fig 8, E and F).

So that we could confirm the results obtained by distributional maps a comparison of environmental factors, mesozooplankton and copepods in these two parts was performed using Mann-Whitney U test (Tab. 2).

During fall, clear differences between northern and southern ranges of temperature were recorded since 'p' value was zero so H_0 (that supposes that southern and northern stations are similar) was rejected. Although in summer, these differences were not statistically significant as 'p' value was higher than 0,05 (Tab. 2).

Similarly, salinity has indicated significant differences between northern and southern stations in both seasons as 'p' ranged from 0,01 (fall) to 0,4 (summer). (Tab. 2).

Concerning cholorphyll'a' concentrations, no significant differences were observed between the north and south part of Dakhla (24°) since 'p' values were higher than 0,05 during both seasons (0,831 in fall and 0,329 in summer). (Tab. 2).

However, mesozooplakton and copepods densities in the northern part were indeed largely different from those noted in the south, which corroborated previous results (Fig 3). For both components, 'p' had a value of zero in fall and was extremely weak in summer (0,001). (Tab. 2).

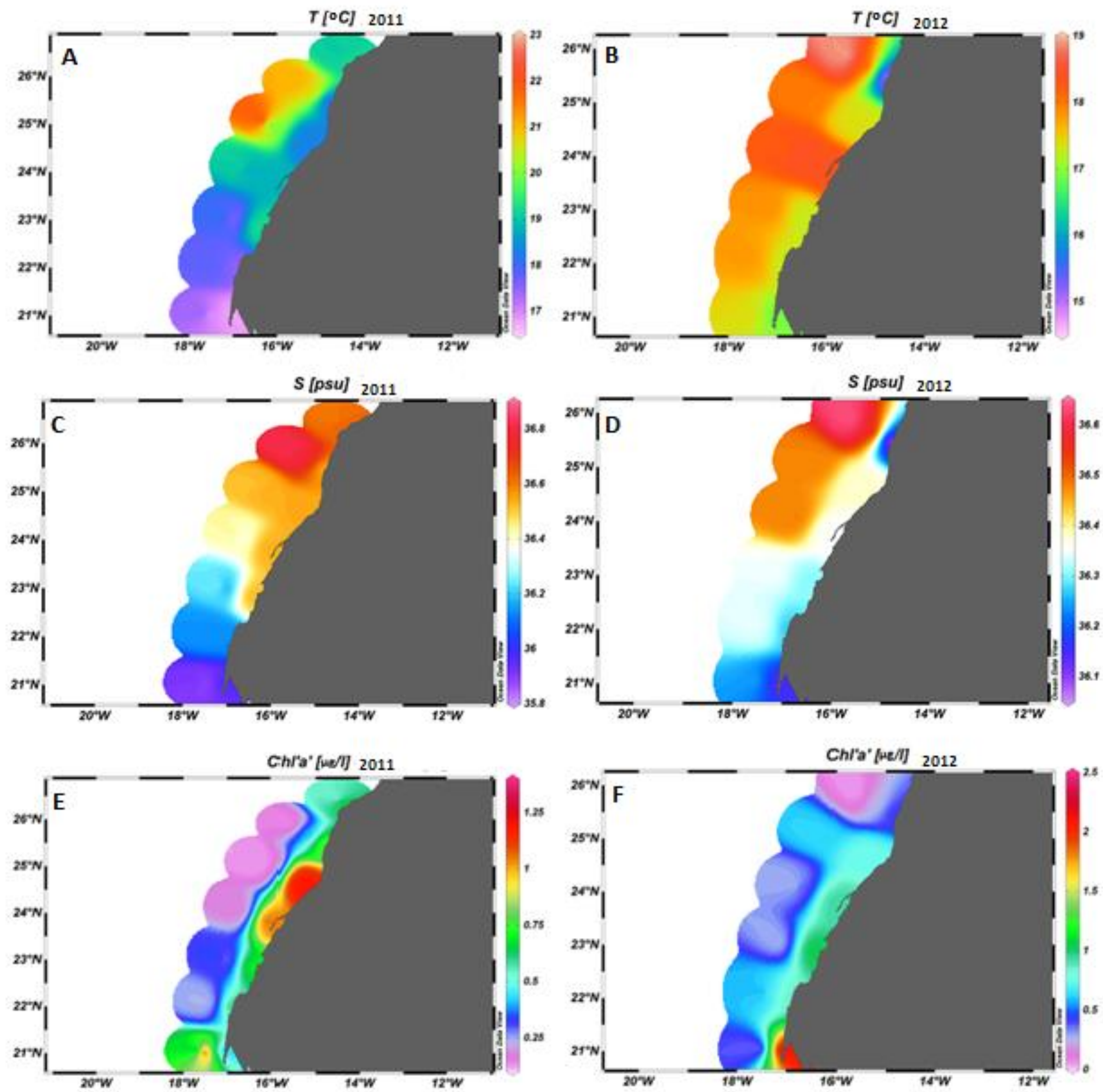

Fig. 8: Distribution maps of salinity (psu), A: during fall season, B: during summer; Temperature (°C), C: during fall season, D: during summer and Chlorophyll'a' (µg/l), E: during fall season, F: during summer.

Table 1: List of identified copepods species during both seasons (+/-: presence of the species or absence during the season):

Species/Season	**Fall**	**Summer**
Acartia clausi (Giesbrecht, 1889)	+	+
Acartia danae (Giesbrecht, 1889)	+	+
Acartia longiremis (Lilljeborg, 1853)	+	+
Aetideus armatus (Boeck, 1872)	+	+

Aetideus giesbrechti (Cleve, 1904)	+	+
Aetidopsis multiserrata (Wolfenden, 1904)	-	+
Arietellus sestosus (Giesbrecht, 1892)	+	+
Calanoides carinatus (Krøyer, 1848)	+	+
Calanus helgolandicus (Claus, 1863)	+	+
Calanus gracilis (Jaschnov, 1955)	+	+
Calocalanus contractus (Farran, 1926)	+	+
Calocalanus pavo (Dana, 1849)	+	+
Candacia armata (Boeck, 1872)	+	+
Candacia bipinnata (Giesbrecht, 1892)	+	-
Candacia varicans (Giesbrecht, 1892)	+	+
Candacia longimama (Claus, 1863)	+	-
Candacia simplex (Giesbrecht, 1889)	+	-
Centropages chierchiae (Giesbrecht, 1889)	+	+
Centropages hamatus (Lilljeborg, 1853)	+	+
Centropages typicus (Kroyer, 1849)	+	+
Centropages violaceus (Claus, 1863)	+	+
Clausocalanus arcuicornus (Dana, 1849)	+	+
Copilia quadrata (Dana, 1849)	+	-
Corycaeus flaccus (Dana, 1849)	+	+
Corycaeus sp	-	+
Corycaeus clausi (Fdahl, 1894)	-	+
Corycaeus typicus (Krøyer, 1849)	+	+
Diaixis pygmoea (Scott, 1899)	+	+
Eucalanus crassus (Giesbrecht, 1888)	-	+
Eucalanus elongatus (Dana, 1848)	+	+
Eucalanus monachus (Giesbrecht, 1888)	+	+

Euchaeta acuta (Giesbrecht, 1892)	+	+
Euchata spinosa (Giesbrecht, 1892)	+	+
Euchata pubera (Sars, 1907)	+	+
Euchirella sp.	+	+
Euchirella rostrata (Claus, 1866)	+	+
Euterpina acutifrons (Norman, 1903)	+	+
Gaetanus tenuispinus (Sars, 1900)	+	+
Heteroptilus aculitobus (Sars, 1905)	-	+
Labidocera sp.	+	+
Labidocera wollastoni (Lubbock, 1857)	+	-
Lubbockia squillimana (Claus, 1863)	+	+
Lucicutia atlantica (Wolfenden, 1904)	+	+
Lucicutia flavicornis (Claus, 1863)	+	+
Lucicutia tenuicauda (Sars, 1907)	+	+
Mecynocera clausi (Thompson, 1888)	+	+
Metridia macrura (Sars, 1905)	+	-
Microsetlla gracilis (Dana, 1848)	-	+
Microsetella norvegica (Boeck, 1864)	+	+
Microsetella rosea (Dana, 1848)	+	-
Monstrilla helgolandica (Claus, 1863)	+	+
Nanocalanus minor (Claus, 1863)	+	+
Oithona helgolandica (Claus, 1863)	+	+
Oithona nana (Giesbrecht, 1892)	+	+
Oithona plumifera (Baird, 183)	+	+
Oithona setigera (Dana, 1849)	+	-
Oncaea mediteranea (Claus, 1863)	+	+
Oncaea venusta (Philippi, 1843)	+	+

Paracalanus nanus (Sars, 1907)	+	-
Paracalanus parvus (Claus, 1863)	+	+
Paraeuchaeta sp.	+	+
Pleuromamma abdominalis (Lubbock, 1856)	-	+
Plreuromamma gracilis (Claus, 1863)	+	+
Pleuromamma xiphias (Giesbrecht, 1889)	+	+
Pseudocalanus elongatus (Boeck, 1872)	+	+
Rhincalanus cornutus (Dana, 1849)	+	+
Rhincalanus nasutus (Giesbrecht, 1888)	+	+
Sapphirina opalina (Dana, 1849)	+	+
Sapphirina sp.	+	+
Scaphocalanus magnus (Scott, 1894)	+	+
Scottocalanus persecans (Giesbrecht, 1895)	+	-
Temora stylifera (Dana, 1849)	+	+
Triconia conifera (Giesbrecht, 1891)	+	+
Xanthocalanus obtusus (Farran, 1905)	+	+

Table 2: Mann-Whitney U test results on northern and southern densities and environmental parameters (temperature, salinity and chlorophyll'a'): Significant differences are shown in **bold** ($p < 0,05$).

Season	**Fall**		**Summer**	
Parameter/Result	U	P	U	P
Temperature (°C)	3	**0**	17	0,079
Salinity (psu)	9	**0,001**	14	**0,04**
Chlorophyl'a'(µg/l)	57	0,831	45	0,329
Mesozooplankton	108	**0**	70	**0,001**
Copepods	108	**0**	70	**0,001**

Discussion and conclusion

During the period of the current study, copepods remained dominant in all sampled stations (more than 90%). Recently, other investigations in the same studied area have also revealed such a large predominance of copepods (Somoue et al., 2005; Zizah et al., 2012).

In fact, this group represents 80% of the total biomass of plankton in the oceans (Verity and Smetacek, 1996).

In total, 76 copepods species were recorded in the studied area. In the same region, Somoue et al. (2005) have reported 78 species during the year 1998 whereas, Zizah et al. (2012) have accounted 85 species of copepods more recently (2007-2009).

During fall the group of copepods was dominated by the species *O. venusta* (44%), *C. arcuicornus* (18%) while *A. clausi* (18%) and *C. arcuicornus* (15%) were the most represented in summer. These three species seem to be very common in the studied area as they have previously been recorded off the Moroccan Atlantic coast (Belfequih, 1980; Chiahou, 1990; Chiahou, 1997; Chiahou and Ramdani, 1997). Moreover, these species are known for being especially abundant during upwelling season at Cape Blanc (21°N).

In fact, the dominance of species in any population differs from one season to another depending strongly on the degree of adaptation of species to physicochemical environmental changes. This has already been highlighted in previous investigations in different areas of the Moroccan Atlantic coast (Belfequih, 1980; Salah, 2013).

Furthermore, mean densities of copepods calculated using Mann-Whitney U test have shown similar results, since they varied from 32320,6 ind/m^3 in the south to 849,73 in the noth area during fall. Similarly in summer, average densities achieved 23454,37 ind/m^3 while they were only about 609,72 ind/m^3 in the north.

Similarly, structure indexes measured have displayed almost similar results as diversity decreased from the south to the north. Moreover, the area of Cape Blanc (21°N) was particularly rich and the population therein was more structured. Actually, Cape Blanc (21°N) is well-known by its richness in zooplankton due to the high quantity of nutrients produced by the quasi-permanent activity of upwelling in this area (Makaoui et al., 2005; Benazzouz et al., 2008). In addition, this region is described as an ecological barrier for planktonic populations and frontal zone where two different water masses NACW (North Atlantic Central Waters) and SACW (South Atlantic Central Water) meet, hence its important richness (Fraga, 1974; Vives, 1974; Weikert, 1984; Mittelstaedt, 1983; Fraga et al., 1985; Binet, 1988; Roy, 1991).

Though, dendrograms and NMDS ordination plots produced have displayed these results, since northern stations were distinctly separated from the stations situated in the south of Dakhla (24°N). Furthermore, these analysis have indicated a distinguish separation between nearshore and offshore stations. This evident difference has already been noted in the Atlantic Moroccan coast concerning mesozooplankton distribution (Salah et al., 2013; Salah, 2013) and copepods distribution (Belfequih, 1980; Somoue, 2004; Somoue et al., 2005) although nearshore ecosystems are usually affected by a turbulent mixing (Petersen et al., 1998).

Environmental factors were also differently distributed between the southern area (21, 22 and 23°N) and northern region of Dakhla (24°, 25°, 26 and 26°30'N), chiefly temperature and salinity. As during fall, distribution maps of these two parameters and Mann-Whitney U test have revealed extremly different ranges between the southern area and northern region of Dakhla (24°N). Whereas, statistically only salinity has indicated a significant difference in summer.

Nevertheless, chlorophyll'a' concentrations did not relveal such significant differences between northern and southern areas during both seasons.

Actually, the southern part of Moroccan Atlantic coast is particularly richer and more diversified than its northern part, especially at Cape Blanc (21°N). Indeed, Zizah et al. (2012) and Somoue et al. (2005) have reported similar results earlier. Usually, in an upwelling system, zooplankton abundances and size structure depend strongly on the intensity of its activity (Rykaczewski and Checkley, 2008).

In conclusion, we have tried to highlight how copepods are distributed off southern Moroccan Atlantic coast. Density differences were observed between northern and southern parts of Dakhla (24°N), the three first transects (21, 22 and 23°N) were distinctly individualized from the rest. This difference is certainly related to the effects of hydrological parameters which also varied between these two parts, mainly temperature and salinity. These results allowed us to set a distinct geographical separation on the surveyed area.

Acknowledgements:

The present study is part of the program CCLME (Canary Current Large Marine Ecosystem), funded by the Global Environment Fund (GEF). Special thanks go to all colleagues who have participated to field work abroad 'Fridjof Nansen', especially to Said Charib, Tarik Baibai, Aziz Agouzoug and Belebchir Youness.

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