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Assessing the Distribution Patterns of Copepods in Relation to Major Environmental Factors in the Canary Current Large Marine Ecosystem (CCLME)

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ABSTRACT

Copepods are the most abundant metazoans in marine ecosystems. They can be regarded as a keystone component of biogeochemical cycles and functioning of pelagic food webs. Their dynamic changes may affect the biomass of many fish stocks. Therefore, it's critical to assess their distribution in this changing climate. The aim of this study was to assess the copepods distribution patterns in relation to environmental factors in the most productive upwelling ecosystem in the world: Canary Current Ecosystem (CCLME) between Cape Blanc (21°N) and Cape Bojador (26°N). Overall, we counted 19 mesozooplankton groups. Copepods constituted the highest fraction in all sampled layers during both investigated seasons (autumn and summer) since they represented at least 65% of the total mesozooplankton community. A cluster analysis allowed the definition of five main species assemblages during each season. The total copepods abundances projected on T/S, T/DO and T/chl-a diagrams showed no clear pattern in densities variation. However, when dominant species were individually projected on T/chl-a diagrams showed different distribution patterns according to their thermic and diet preferences. Multiple Analysis Factorial analysis performed between dominant species densities and major environmental factors revealed a clear positive correlation between most of species and chl-a concentration during both seasons; most of these species were phytophagous. Our finding shows that temperature and chl-a concentration seem to be the most important environmental factors and thus strongly influence the distribution of the copepod population in the CCLME. To further investigate the relationship between copepods and environmental factors we suggest adding upwelling index, which may be responsible for the major changes found in copepod distribution.

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Introduction

Copepods are the most abundant metazoan grazer in marine ecosystems. They occupy a pivotal position within the pelagic ecosystem [1] and particularly in the upwelling systems such as the Canary Current Large Marine Ecosystem (CCLME) [2, 3]. Copepods can be regarded as a keystone component of biogeochemical cycles and functioning of pelagic food webs [4, 5, 6, 7].

In the CCLME, and particularly in the Moroccan Atlantic coast, copepods account for 60-95% of the total zooplankton abundance [8, 9, 10, 11, 12, 13]. Similar observations have also been recorded in other upwelling systems of the world such as Peru [14, 15, 16]. There is apparently a strong correlation between the intensity of the upwelling and the abundances, size structures and distribution of zooplankton in coastal areas [8, 17, 18].

Moroccan Atlantic coast between $21^{\circ}N$ and $26^{\circ}N$ is submitted to a constant increasing upwelling activity [19]. This region is known for high fish production (1,312,300 mt

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in 2015) mainly composed of clupeidae, scombridae, carangidae and engraulidae [20, 21]. The epipelagic mesozooplankton; particularly copepods; constitute the principal prey for the two most abundant small pelagic fish species found throughout the Moroccan Atlantic coast (anchovy and sardine) [22, 23, 24, 25, 26, 27, 28]. Potentially, mesozooplankton (copepods) play important an trophodynamic and economic role, since their dynamic changes may affect the biomass of many fish stocks [29, 30]. Therefore, it is important to quantify continuously the dynamic of mesozooplankton in relation to environmental factors that are changing dramatically in recent decades. Several studies have shown that zooplankton can even be used as an indicator of global climatic change because of it quick response to environmental fluctuations [31, 32, 33]. Mesozooplankton abundances and spatial distribution in relation to environmental factors such as temperature, salinity, chlorophyll, nutrients, nature of water masses and turbulence have been extensively studies [34, 35, 36, 37, 38,

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39, 40, 41, 42]. According to Valdés and Moral [43], the seasonal variability of copepods is closely related to the variability of water column properties and phytoplankton dynamics. Therefore, in order to understand the distribution patterns of their communities, it is necessary to study hydrological characteristics of the area [44].

Copepods are traditionally considered as herbivorous and depend on chl-*a* availability since they are generally more abundant in water columns rich of phytoplankton [45]. It has even been suggested that seasonality in phytoplankton production controls zooplankton seasonality [46, 47].

The aim of this investigation are: 1) provide a general overview of the composition of mesozooplankton supposing that copepods constitute the major group; 2) show the taxonomic segregations between copepods species by performing a cluster analysis of species assemblages ; and 3) detect changes in copepods distribution in relation to environmental factors by projecting copepods densities on environmental factors diagrams, and applying a Multiple Analysis Factorial between copepods densities and environmental factors.

Material and Methods

1. Sampling

Mesozooplankton and environmental data were collected during autumn 2011 (November) and summer 2012 (July) in Moroccan Atlantic coast between 21°N and 26°N along six transects on board the Norwegian R/V "Dr. Fridtjof Nansen" (Fig. 1).





Samples were collected from 5 distinct layers of the water column; from the epipelagic zone (0-25m, 25-50m, 50-75m, 75-100m and 100-200m) using a Multinet (160 μ m mesh, 50 x 50 cm mouth size). As each net is opened and closed independently, contamination is apt to be negligible [48].

All samples were preserved in 5% buffered formalin for further determination. Environmental parameters (temperature, salinity, and dissolved oxygen) were measured in situ deploying a multiprobe CTD connected to a computer from which the recorded data is extracted. chl-*a* concentration was measured in the laboratory by a fluorimetric method [49]. **2. Samples treatment:**

Identification and mesozooplankton's enumeration were made under a binocular stereoscope referring to appropriate systematic keys [50, 51, 52, 53]. To facilitate identification, a Motoda box was used [54].

Densities were expressed as individuals per cubic meter (ind. m^{-3}). They were calculated as follows: D = (n '1000) / V

With D being the density (expressed in individuals per liter), n the number of individuals found per volume of water and V the filtered water volume (m^3) .

Dominance Index (X) was calculated for all recorded species, in order to take into account only dominant ones in the following analyses. It corresponds to the frequency of their occurrence: $Xi = (Ni/N) \times fi$

Where Xi is the dominance of species i, N_i is the number of individuals of species, N is the number of individuals of all species at all locations, fi is the frequency of locations at which species i occurs. Only species with X value ≥ 0.02 were accounted as dominant [55, 56].

Projection of copepods densities of each sample on Temperature-Salinity (T/S), Temperature-Dissolved Oxygen (T/DO) and Temperature-chl-a (T/ chl-a) diagrams were constructed from data collected during both seasons.

Non-metric cluster analyses were applied in conjunction with the Bray-Curtis similarity index in order to point out copepod species associations. The density (ind.m⁻³) was square-rooted transformed prior to the analysis to reduce bias caused by extremely abundant species.

Significance levels and sources of differences among copepod assemblages were tested using the analysis of similarity (ANOSIM) and similarity percentage (SIMPER) using Plymouth Routines in Multivariate Ecological Research (PRIMER) computer package.

To identify species affinities to environmental parameters, a Multiple Factor Analysis (MFA) was performed using the software SPAD7.4 (Set Program Access and Computer Defaults).

The MFA is based on global analysis of k tables on the same stations; k groups of variables belonging to the same group of individuals are compared. Its purpose is to obtain a typology of individuals, variables and links between the two types [57].



1. Mesozooplankton composition and Copepods assemblages

Over both sampling periods, 19 groups of mesozooplankton were counted.



Figure 2. Relative abundances of mesozooplankton in each level per transect (N1: 0-25m, N2: 25-50m, N3: 50-75m, N4: 75-100m, N5: 100-200m).

Autumn	Code	Summer	Code
Acartia danae (Giesbrecht, 1889)	ACDA	Aetideus armatus (Boeck, 1872)	AEAR
Calanoides carinatus (Krøyer, 1848)	CACA	Aetideus giesbrechti (Cleve, 1904)	AEGI
Candacia varicans (Giesbrecht, 1892)	CAVA	Calanus finmarchicus (Claus, 1863)	CAFI
Pleuromamma gracilis (Claus, 1863)	PLGR	Centropages violaceus (Claus, 1863)	CEVI
Triconia conifera (Giesbrecht, 1891)	TRCO	Paracalanus parvus (Claus, 1863)	PAPA
		Rhincalanus nasutus (Giesbrecht, 1888)	RHNA
1	Species in	common	
Acartia clausi (Giesbrecht, 1889)	ACCL	Microsetella rosea (Dana, 1848)	MIRO
Agetus flaccus (Giesbrecht, 1891)	AGFL	Nannocalanus minor (Claus, 1863)	NAMI
Agetus typicus (Krøyer, 1849)	AGTY	Oithona similis (Claus, 1866)	OISI
Calocalanus contractus (Farran, 1926)	CACO	Oithona nana (Giesbrecht, 1892)	OINA
Candacia armata (Boeck, 1872)	CAAR	Oithona plumifera (Baird, 183)	OIPL
Centropages chierchiae (Giesbrecht, 1889)	CECH	Oncaea mediterranea (Claus, 1863)	ONME
Centropages typicus (Kroyer, 1849)	CETY	Oncaea venusta (Philippi, 1843)	ONVE
Clausocalanus arcuicornis (Dana, 1849)	CLAR	Pleuromamma xiphias (Giesbrecht, 1889)	PLXI
Eucalanus elongatus (Dana, 1848)	EUEL	Temora longicornis (Müller, 1785)	TELO
Euterpina acutifrons (Norman, 1903)	EUAC	Temora stylifera (Dana, 1849)	TEST
Lucicutia flavicornis (Claus, 1863)	LUFL		

Table 1. List of utilinant species with their respective cour	Table 1. List of	dominant	species v	with t	their	respec	tive	code
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As expected, copepods were numerically dominant. Their proportion was actually higher than 65% among the total relative abundances of different groups within the water column during both seasons. During autumn, Cladocera was the most dominant group after copepods. Their important abundances were more pronounced between Dakhla (24°N) and Cape Bojador (26°N). A maximum of Chaetognatha abundances were found in upper layers at Cape Blanc (21°N) in autumn and within Dakhla region (24°N) in summer. The other groups presented low densities; their relative abundances did not exceed 0.2% (Fig. 2).

As copepods group was markedly the most important, their identification was made down to species level. In total, 72 species were recorded during autumn against 67 in summer. According to dominance index calculated, 21 taxa commonly dominated copepods community during both seasons while only 5 species were dominating during autumn against 6 in summer (see table 1).









Cluster analyses were performed in order to exhibit copepod species assemblages. According to this hierarchical classification, copepod species were classified into five clusters. Among species occurred during both cruises, we took account only dominant species to run the analysis. They counted for 26 in autumn versus 27 in summer. The dendrograms resulting from the cluster analysis revealed at 25% of Bray-Curtis similarity level, the presence of 2 major groups of species during both seasons. Whereas at 45% of similarity level, a striking separation of copepod community into 5 distinguished groups was apparent (Fig. 3 and 4).

During both seasons, the number of copepod species was not equally distributed across the 5 occurring groups. A single group was formed by more than 50% of total species while the other groups contained from 1 to 4 species. We also have observed that the two species *O. venusta* and *C. arcuicornis* were associated and made up a single group during both seasons.

2. Copepods and environmental factors

During both seasons, the projection of copepods densities on T/S diagram has shown that the highest copepods densities occurred within the locations where temperature ranged from $16,5^{\circ}$ C to $19,5^{\circ}$ C. As to salinity, higher densities were restricted to narrow ranges: 35,9-36,5 psu. Although, during autumn, low copepods densities were observed across important values of temperature and salinity, exceeding respectively $20,5^{\circ}$ C and 36,75 psu (Fig. 5, A).

Equally, on T/DO diagram high copepods densities were recorded across mean values of temperature and high ranges of dissolved oxygen (> 3,5) during both seasons (Fig. 5, B).

T/chl-a diagram has shown irregular distribution of

copepods across wide ranges of temperature during both seasons whereas important densities were observed within stations of high chl-*a* concentration in summer (Fig. 5, C).

Through these bivariate diagrams, no clear copepods distribution pattern was deduced as their preferential ranges of temperature, salinity, oxygen or chl-*a* were not discernable. Since this group is widely diversified, the relationship between recorded copepods species and environmental parameters (temperature, chl-*a*, salinity and dissolved oxygen) was analyzed employing a Multiple Factor Analysis.

During autumn, the factorial plan F1XF2 presented 24,83 % of total inertia at the rate of 15,86 % for F1 axis and 8,97 % for F2 axis.

Actually, several species were associated to greater chl-a concentrations as Acartia clausi, Oithona similis, Euterpina acutifrons, Agetus typicus, Microsetella rosea, Triconia conifera, Temora longicornis and Centropages chierchiae.

Whereas, on the opposite side species whose densities varied with higher temperature, salinity and oxygen were pointed out: Onceae venusta, Pleuromamma xiphias, Agetus flaccus, Acartia danae, Eucalanus elongatus, Temora stylifera and Calocalanus contractus.

Also during that season, few other species did not show any affinity with hydrological parameters as *Onceae mediteranea*, *Clausocalanus* arcuicornis, *Lucicutia flavicornis* and *Oithona plumifera* (Fig. 6, A).

<u>During summer</u>, the factorial plan F1XF2 presented 32,16 % of total inertia at the rate of 18,60 % for F1 axis and 13,56 % for F2 axis.







Figure 6. MFA between copepod densities (ind/m⁻³) and hydrological parameters (temperature (°C), salinity (psu), Chl-*a* (mg/m⁻³) and dissolved oxygen (ml.l⁻³)) in autumn (A) and summer (B).

Closely correlated to chl-*a* concentrations, about ten species were reported: *A. clausi, Paracalanus parvus, Oithona nana, T. longicornis, Centropages violaceus, Calanoides carinatus, C. typicus* and *O. similis.*

Species associated to high temperature, salinity and oxygen rates were represented by *O. venusta*, *Oithona plumifera*, *T. stylifera*, *E. elongatus* and *C. chierchiae*.

Nevertheless, abundances of others species were not associated of hydrological factors as *Nannocalanus minor*, *Pleuromamma xiphias*, *Aetideus giesbreshti* and *L. flavicornis*.

Moreover, we have noticed that some species in common for both seasons were correlated to the same parameter as *A*. *clausi*, *E*. *acutifrons* and *O*. *similis* in relation to chl-*a* concentrations (Fig. 6, B).

As most of species were correlated to chl-*a* concentrations, densities of each species forming individual groups; resulting from the above hierarchical classification; were singly projected on T/chl-*a* in order to assess the relationship between these species and both parameters.

<u>During autumn</u> the first group had a single species: *C. typicus*. Its highest densities were conspicuous where temperature ranged from 17 to 19° C and across wide ranges of chl-*a* concentrations.

The three species constituting the second group were all

of them widely distributed across both temperature and chl-*a* ranges.

The third group species have shown a wide distribution across temperature but were more abundant where salinity was around 0.5 mg.m^{-3} .

The species of the fourth group were equally distributed over wide ranges of both parameters, excepting *C. contractus* which was abundant at low values of temperature and chl-*a*.

Most of species occurring in group 5 were widely distributed over both temperature and salinity ranges as well, excepting *O. similis* and T. *conifera* whose densities were important at very moderate values of chl-*a* (Fig. 7).

<u>During summer</u>, group 1 included species that varied with large ranges of chl-a and were more important over a narrow range of temperature. The same observations were made for most of species making up the second group.

The third group was formed by of *O. similis*, its highest densities were relatively more abundant across very narrow ranges of temperature $(17-17,5 \ ^{\circ}C)$ and wide ranges of chl-*a*.

The species making up the fourth group were relatively more abundant across narrow ranges of both parameters.

Species forming group 5 were widely distributed over both temperature and chl-*a* except *A*. *clausi* whose high densities were mainly recorded at locations with high chl-*a* concentration (Fig. 8).



Chlorophyll-a (mg.m⁻³)



Figure 7. Copepod species densities (ind.m⁻³) projected on T/Chl-*a* diagrams during autumn 2011.





Figure 8. Copepod species densities (ind.m⁻³) projected on T/Chl-*a* diagrams during summer 2012. Discussion and conclusion group to another. During summer, the stenothermic

In this investigation, 19 groups of mesozooplankton were identified. As expected, the group of copepods was by far the most abundant through the water column and within all sampled stations during both sampling periods. This corroborates previous results of investigations carried out off the same area where copepods contributed more than 70% [9, 11, 58]. Similar prevailing species therein were already reported as dominant within this region by Somoue et al. [9]. Equally, some significant components of upwelling systems of the Atlantic Ocean were listed as C. carinatus, Calanus finmarchicus and A. clausi. Analyzing assemblages of species on hierarchical classification displayed associations between most of species with similar diets. The largest group (G5) was formed by herbivorous or preferentially herbivorous species as, L. flavicornis, N. minor, E. elongatus, A. clausi and T. longicornis [59, 8, 55]. By contrast, G3 is formed by two omnivorous species P. xiphias and A. danae were associated in G3 during autumn while in summer, two carnivorous species occurred in G1: C. typicus and O. mediteranea [55]. The projection of total copepods densities on T/S, T/DO and T/Chl-a diagrams has shown no clear distribution patterns in densities variation over the seasons since densities were scattered across large ranges of these parameters. Tough, according to Belfequih [8], the development of some copepod species is closely related to temperature in the Moroccan Atlantic coast. As well, this parameter could determine in some cases zooplankton's production [60]. Copepods species in relation to temperature and chl-a as reflected on T/Chl-a diagrams have shown different distribution patterns from a group to another. During summer, the stenothermic species A. clausi was very abundant and was distributed across narrow ranges of temperature. It is actually a species preferentially herbivorous enable to feed on low phytoplankton concentration, which explains its great abundance at locations of high chl-a concentration. Moreover, it presents one of the most abundant copepods off Moroccan Atlantic coast [8, 61, 9, 10, 62]. The taxa C. typicus varied across wide ranges of temperature and varied positively with chl-a in both analysis. This species is reported as eurythmic and omnivorous, feeding principally on phytoplankton [8, 63]. Although O. venusta and C. arcuicornis had different diets, these two species were associated and made up a single group during both seasons. This should certainly be owing to their eurythermic and euryhaline characteristics [8] Belfequih. The MFA analysis, revealed a significant correlation between chlorophyll "a" concentration and most of copepod species, confirming the strong relationship between abundances of mesozooplankton and chlorophyll "a" set by Gotsis-Skretas et al. [64]. A number of species was in common between both seasons and have shown a close affinity to chl-a concentration. This group included many herbivorous species as A. clausi, T. longicornis, C. typicus, E. acutifrons and O. similis. The species C. chierchiae; that appears during autumn; is an herbivorous often encountered in upwelled areas [8]. Earlier, Longhurst [65] has demonstrated the important link between subsurface chl-a and vertical distribution of zooplankton. During summer, C. carinatus was closely associated to high chl-a values and negatively correlated to temperature, salinity and oxygen.

Which suggest the linkage of this species with fresh upwelled waters characterized by low salinity and dissolved oxygen. This species is actually strictly herbivorous and has been reported in relation to upwelling [66, 8, 67]. Indeed, in this area upwelling activity is more intense during summer [68]. O. venusta has been ranked as an omnivorous and a detritivores species generally present within superficial layers [69, 70], which explains its association to high values of temperature and its negative relation with chl-a during both seasons. Salah [12] (2013) has also reported the presence of O. venusta within warm waters containing low chl-a concentrations in cape Juby (Fig. 1). Other species appeared to be positively correlated to chl-a only during summer but no particular trend related them in autumn, as *O*, *nana* and *P*. parvus. Actually, O. nana is ranked as a cosmopolitan species with preferentially herbivorous diet while *P. parvus* is strictly herbivorous [71, 72]. Moreover, P. parvus was defined as a warm-water species by Greze et al. [73] (1971) which explains its occurrence during the hot season and its abundance in stations characterised by high temperature and chl-a concentration (T/Chl-a diagram). Earlier, Belfequih [8] has also demonstrated the link existing between copepods diet and phytoplankton abundances in upwelled regions of Moroccan coast. In fact, their production depends mainly on phytoplankton availability [74, 75] which proves our results from the MFA between copepods and environmental factors. However, particular conditions prevail in the studied area. The important upwelling activity makes this area as the most productive region of the Moroccan Atlantic coast [76, 67, 77, 78, 79]. Therefore, such a complex system is characterized in one hand by the presence of a thermal front separating ESAW (Eastern North Atlantic Waters) from ENAW (Eastern North Atlantic Waters); on the other hand by the presence of a permanent upwelling activity of which the maximum intensity is observed during summer [80, 68]. This phenomenon is apparently responsible of chl-a and zooplankton exportation offshore [81, 82, 83]. Our results suggest that most of copepods species have shown a clear relationship with temperature and especially chl-a. To further examine the direct relationship between copepods and environmental factors, and to develop numerical models to assess the behavior of zooplankton with changing climate in such a complex upwelling system will require longer time series data on copepods densities, distribution and environmental factors. We also recommend including upwelling index data, which we think is responsible for the major changes found in copepod distribution.

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