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ORIGINAL RESEARCH ARTICLE

Short-term variation of zooplankton community in Cintra Bay (Northwest Africa)

Amina Berraho*, Hinde Abdelouahab, Tarik Baibai, Said Charib, Jamila Larissi, Aziz Agouzouk, Ahmed Makaoui

National Institute of Fisheries Research, Casablanca, Morocco

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Summary This is the first study that describes the spatial-temporal distributions of the zooplankton community and potential control factors in Cintra Bay. Zooplankton were sampled using a bongo net, 150 μm mesh size, during two surveys, in autumn 2015 and spring 2016, extending from the coast to the open sea. Fourteen zooplankton groups were identified, where copepods represented 49.1% and 92.5% of the total abundance in autumn 2015 and spring 2016, respectively. Tintinnids accounted for 39.7% and 4.7%, respectively. The total zooplankton abundance was higher in autumn (55 992 ind m^{-3}) than in spring (2123 ind m^{-3}). Nineteen species of copepods, belonging to 14 families, were identified. *Euterpina acutifrons* and *Oithona nana* were the most common and abundant species. The Acartiids were represented by three species (*Acartia clausi*, *A. tonsa* and *A. biflosa*) in autumn and one species in spring (*A. clausi*). The copepods diversity was significantly different between the two seasons showing high values at the entrance and the center of the bay in autumn 2015 and in the southern half of the bay in spring 2016. The copepod structure was characterized by 13 species at different degrees of contribution in autumn 2015. In spring 2016, only four species qualified as indicator species although their contribution was not significant. Given its large opening

* Corresponding authors at: Département d'Océanographie, Institut National de Recherche Halieutique, Boulevard Sidi Abderrahmane, 2 Aï Diab, 20240, Casablanca. Tel.: +212522397385; fax: +212522397388.

E-mail addresses: aminaberraho@gmail.com (A. Berraho), hind.abdelouahab@gmail.com (H. Abdelouahab), baibaitarik@gmail.com (T. Baibai), saidcharib@gmail.com (S. Charib), larissijamila@gmail.com (J. Larissi), oceanosaad@gmail.com (A. Agouzouk), oceanomakaoui@gmail.com (A. Makaoui).

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on the ocean, Cintra Bay benefits largely from the conditions of the oceanic environment, particularly the upwelling. This situation is likely to have an impact on the spatiotemporal variability of the composition and distribution of zooplankton, especially the copepods.

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1. Introduction

In Northwest Africa, the Moroccan coastal zone includes several lagoons, estuaries and bays that present a high potential for socio-economic development. Located between Dakhla Bay and Cape Barbas, Cintra Bay is currently one of three geographical areas identified in the Oued Eddahab region (Dakhla Bay, Cintra Bay and the area between them) that would benefit from a large regional aquaculture development program. Cintra Bay is part of the marine ecosystem, influenced by the cold Canary Current and trade winds that generate a quasi-permanent upwelling. In addition to the upwelling effect, this region is influenced by the contribution of the South Atlantic Central Waters (SACW), characterized by low salinities and high nutrient content (Makaoui et al., 2005). This makes the area one of the richest fishing grounds in the world, mainly for small pelagics, and Cintra Bay serves as a spawning ground for several species (Ettahiri et al., 2012).

The first investigations of the coastal ecosystem of Cintra Bay, which began in 2015, described the marine circulation in the bay (Hilmi et al., 2017) and its hydro-sedimentary characteristics (Makaoui et al., 2017). No studies on plankton biodiversity (phytoplankton and zooplankton) were done. These two biological components play a key role in the trophic web and any change in their abundance or structure leads to significant disturbances in the ecosystem structure and functioning (Keister et al., 2012; Paturej and Kruk, 2011). Indeed, because of its strong integration to the environment and its quick response to environmental changes, zooplankton is currently a tool for monitoring the quality of aquatic environments, especially in coastal areas (Abdul et al., 2016; Davies, 2009; Etilé et al., 2015; Jose et al., 2015; Wokoma, 2016). The composition, abundance, and distribution of zooplankton species in any particular aquatic habitat usually provide information on the prevailing physical and chemical conditions in that habitat (Jakhar, 2013); hence, they are of great ecological importance (Abdul et al., 2016; Jose et al., 2015). Several studies have shown that the structure and abundance of zooplankton were closely correlated with the trophic state of the coastal ecosystems, known for their high environmental parameter variability (Kudari and Kanamadi, 2008; Paturej, 2006; Paturej and Kruk, 2011; Pinto-Coelho et al., 2005; Uriarte and Villate, 2005; Wang et al., 2007).

The main aim of the present work is to investigate the zooplankton community structure of Cintra Bay, which will allow for the establishment of the first taxonomic list of zooplankton groups with emphasis on the copepods. Hence, in this study, a description of the spatio-temporal variations of the composition, distribution and abundance of zooplankton groups and copepods species in relation to studied environmental parameters will be discussed.

2. Material and methods

2.1. Study site and sampling network

Having the form of a half-moon oriented NE-SW, Cintra Bay is wide open to the ocean (18 km) and its periphery consists of a very large sandy beach, which contains many dunes of low height, limited by Punta de las Raimas to the north and Punta Negra to the south. Its coastline is sparsely populated, thus leaving the wild areas mainly undisturbed. Mainly governed by wind and semidiurnal tides, the intensity of the currents outside the bay are generally strong (mainly $>0.5 \text{ m s}^{-1}$). Inside the bay, their intensity is less pronounced ($<0.3 \text{ m s}^{-1}$) and generally oriented toward the south of the bay due to the influence of the trade winds (NE) (Hilmi et al., 2017) (Fig. 1). Due to this circulation pattern and the depth of the bay, increasing from the coast ($\approx 5 \text{ m}$) to the open sea ($\approx 13 \text{ m}$) (Makaoui et al., 2017), the influence of open ocean waters is more pronounced at the entrance of the northern part of the bay.

Two oceanographic surveys were conducted in Cintra Bay in autumn 2015 (11–15 October) and spring 2016 (8–11 May) and sampling was carried out in 13 stations covering the entire bay (Fig. 2).

2.2. Sampling and sample processing

Zooplankton was sampled using a plankton net (30 cm aperture, 2.5 m total length and 150 μm mesh size) equipped with a flow meter for calculating the volume of the filtered water. The net was towed horizontally at high tide and samples were preserved in 5% formaldehyde-seawater solution, previously buffered with CaCO_3 .

In the laboratory, zooplankton samples were fractionated using a Motoda box-splitter (Motoda, 1959) where the number of fractions is related to the sample consistency. This operation allows better identification and enumeration of specimens under a stereo microscope. Taxonomic identification of copepods was performed to the species or genus level, but only to the groups for other zooplankton specimens, given their low abundance. Zooplankton and copepod abundances were expressed as individuals per cubic meter [ind m^{-3}].

Surface environmental parameters were collected at the same time as zooplankton sampling. Temperature (T), salinity (Sal) and dissolved oxygen (O_2) were measured in situ with a multi-parameter probe (Hanna, HI9828 Multiparameter Water Quality Meter). At each station, water samples were collected with Niskin bottles. A volume of 500 ml of sampling water was filtered on GF/F filters for the determination of surface chlorophyll-*a* (Chl-*a*) concentration using a fluorimeter (Turner Designs 10 AU) and 30–50 ml of filtered water were used to determine surface nutrients, nitrates

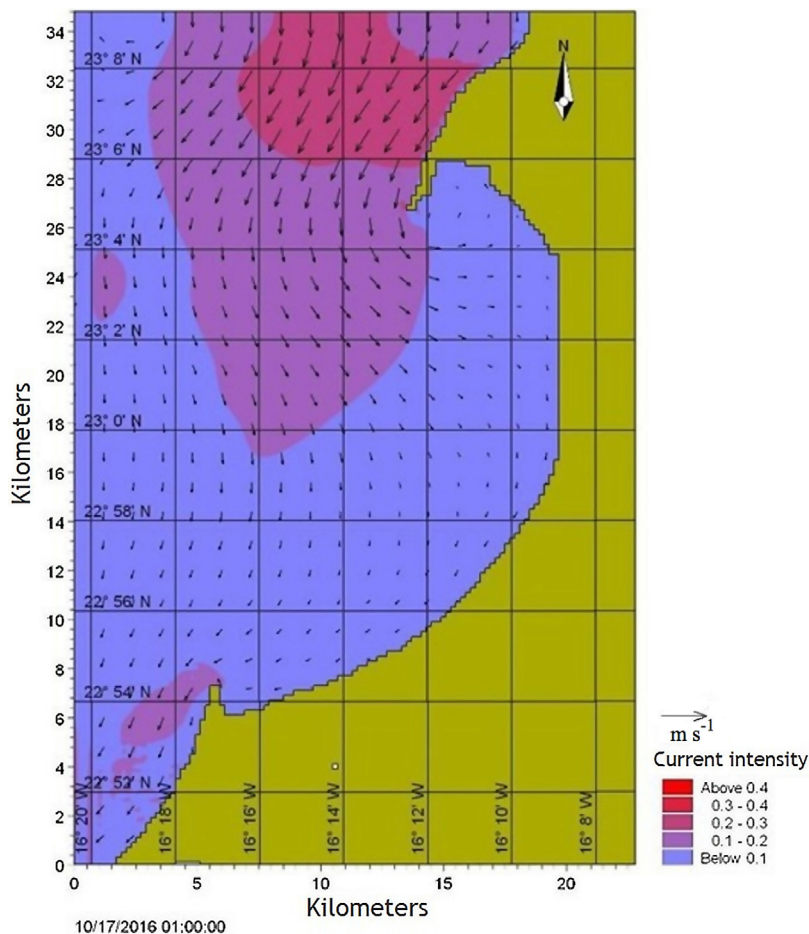


Figure 1 Circulation and current intensity in Cintra Bay during high tide (Hilmi et al., 2017).

(NO₃), nitrites (NO₂), phosphates (PO₄) and silicates (SiO₂) using an Auto Analyzer (AA3 AxEFlow).

2.3. Data analysis

Species diversity of copepods was assessed with the Shannon–Wiener diversity index (H') (Shannon and Wiener, 1949) according to the following formula:

$$H' = -\sum_{i=1}^S p_i \log_2 p_i,$$

where S is the total number of copepods species recorded in the sample (species richness) and p_i is the relative frequency of the species i .

Indicator species analysis (Dufrene and Legendre, 1997) was conducted to identify potential indicator species of copepod for particular environmental conditions in each period. Indicator Value ($IndVal$) for each species i in the group j were computed using the following equation:

$$IndVal_{ij} = RA_{ij} \times RF_{ij} \times 100.$$

RA_{ij} and RF_{ij} are respectively the relative abundance and the relative occurrence for species i in group j (period in our study). A threshold $IndVal \geq 25\%$ and $p < 0.05$ were used as a

cutoff for the indicator species (Dufrene and Legendre, 1997).

The proportion of samples in which the species is recorded determines the frequency of occurrence of a given species.

The relationships between environmental variables and the abundance of both zooplankton groups and copepod species were determined using a Canonical Correspondence Analysis (CCA). The data matrix was composed of abundances transformed into $\log(x+1)$ and the environmental parameters (T, Sal, NO₃, NO₂, PO₄, SiO₂, O₂ and Chl-*a*) of the surface layer. The results were presented as a biplot, in which the biological variables and environmental variables were represented together. The correlations between biological and environmental variables were tested using the Spearman correlation test.

Additionally, a one-way analysis of variance (ANOVA) and a multivariate analysis of variance (MANOVA) were used to determine whether there were significant differences in zooplankton/copepod abundances and in environmental variables between different periods in the study area.

All statistical analyses were performed using R (R Development Core Team 2013), except CCA that was produced using XLSTAT (statistical analysis software version 2018).

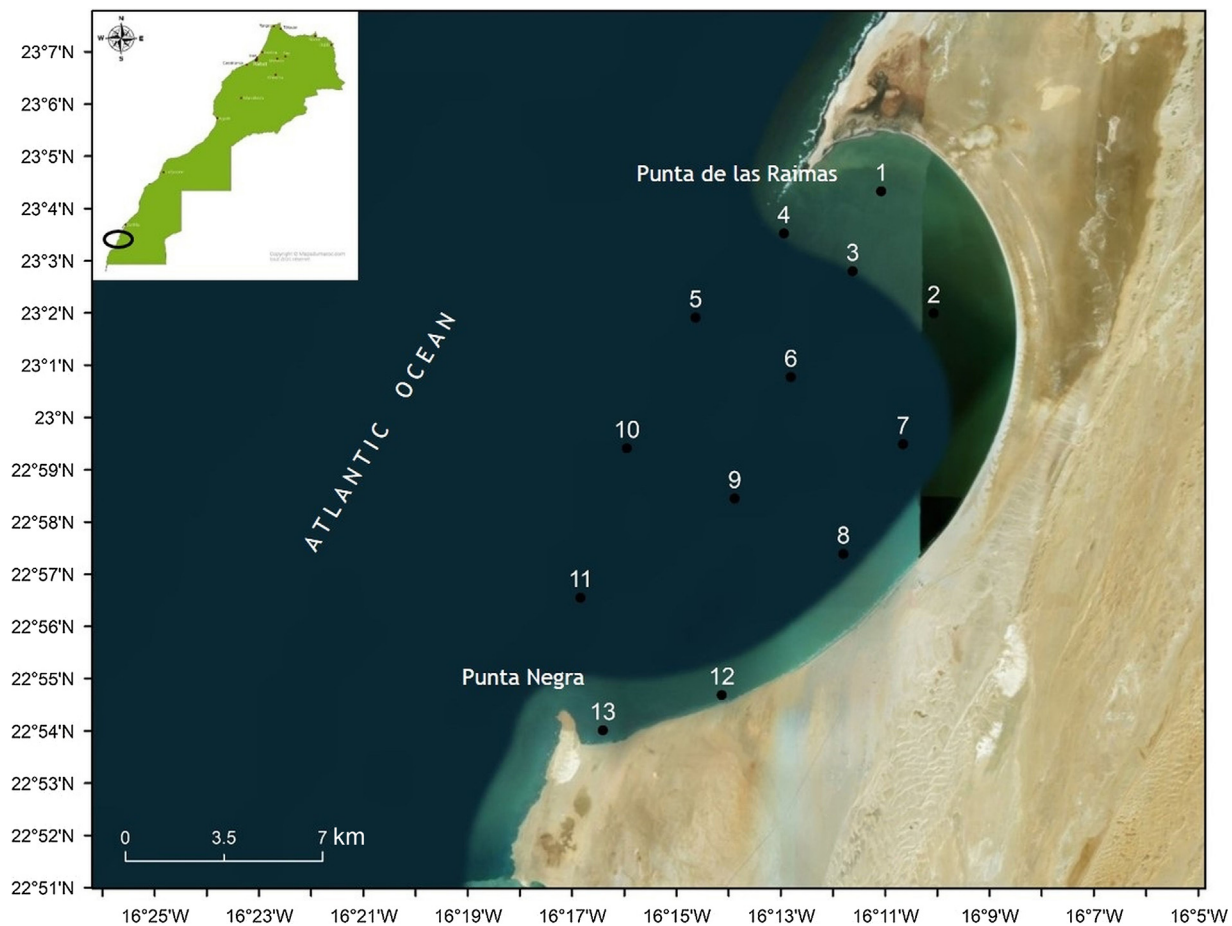


Figure 2 Location of the Cintra Bay (top left) and position of the stations sampled in 2015 and 2016.

3. Results

3.1. Environmental parameters

The average surface temperature recorded in autumn 2015 was relatively high ($21.8 \pm 1^\circ\text{C}$) compared to spring 2016 ($20.1 \pm 1^\circ\text{C}$). During both seasons, the lowest temperatures were recorded in the middle of the bay and at the entrance. In autumn 2015, these low temperatures were spatially limited to the open part of the bay; while in spring 2016, the cooler offshore waters invaded almost the entire bay with the exception of the northern part and some southern areas where the temperature was over 21°C (Fig. 3a). The seasonal variation of surface temperature was highly significant (MANOVA, $p < 0.001$) (Table 1).

Similarly, the seasonal variation of surface salinity was significant with high levels observed in autumn 2015 (average: 36.81 ± 0.41 psu) compared to spring 2016 (average: 36.52 ± 0.09 psu). Spatially, the distribution of salinity in autumn was characterized by an area of high values recorded in the northern part whereas low salinities were observed particularly at the entrance of the bay (stations 5 and 6). In the rest of the bay, salinities were mid-range (Fig. 3b).

The concentrations of surface nutrients (nitrates, nitrites, phosphates and silicates) did not show significant variations

between the two sampling periods (Table 1), with the exception of phosphates. The concentrations of phosphates were significantly higher in autumn 2015 than in spring 2016 (MANOVA, $p < 0.05$). The averages were 0.59 ± 0.39 and $0.28 \pm 0.13 \mu\text{M}$, respectively.

In autumn 2015, nitrates, nitrites and phosphates (Fig. 3c–e) showed similar distributions in the bay with low concentrations in the central part and near Punta Negra, in the southern part. High concentrations were essentially distributed at the entrance of the bay (starting at station 10) and in the northern part of the bay. The spatial distribution of silicates was slightly different, showing low concentrations limited to the central area, while the rest of the bay was rich in silicates (Fig. 3f).

Non-significant differences in dissolved oxygen content were observed between the two seasons (MANOVA, $p > 0.05$) whose averages in autumn 2015 and spring 2016 were 6.58 ± 0.91 and $5.94 \pm 0.53 \text{ mg l}^{-1}$, respectively. The spatial distributions were similar, characterized by well-oxygenated waters in the center of the bay and the least oxygenated waters at the entrance, near Punta de las Raimas (Fig. 3g).

The surface chlorophyll-*a* concentrations showed a highly significant variation between the two seasons (Table 1). In autumn 2015, the bay waters were very rich in phytoplankton; chlorophyll-*a* concentrations were ranging from 1 to $2.72 \mu\text{g l}^{-1}$ while in spring 2016 the concentrations did not

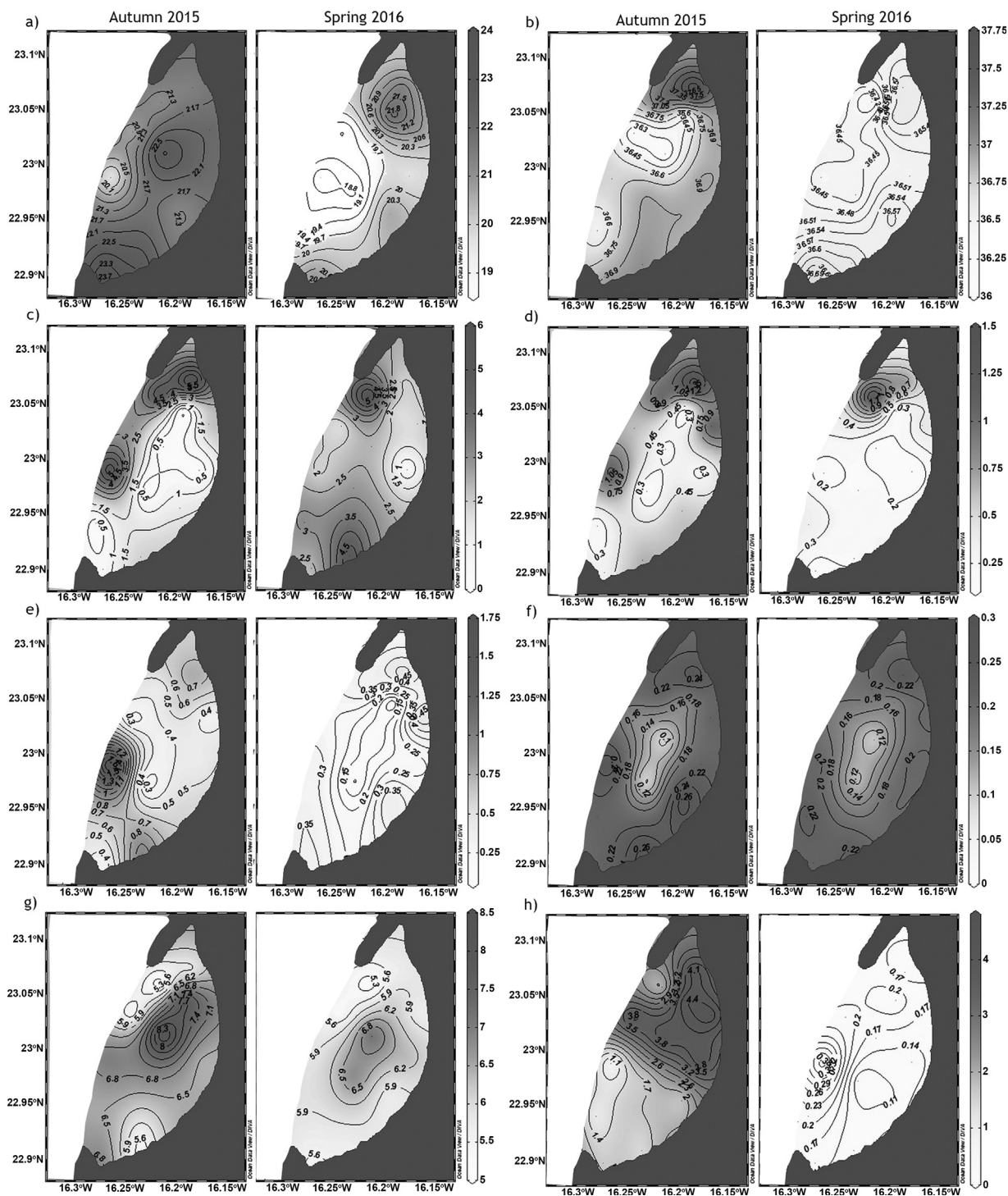


Figure 3 Spatial distribution of the surface temperature [°C] (a), salinity [psu] (b), nitrates [μM] (c), nitrites [μM] (d), phosphates [μM] (e), silicates [μM] (f), dissolved oxygen [mg l^{-1}] (g) and chlorophyll-*a* [$\mu\text{g l}^{-1}$] (h) in autumn 2015 and spring 2016.

exceed $0.39 \mu\text{g l}^{-1}$. According to the spatial distribution of chlorophyll-*a* in autumn 2015, the bay was subdivided into a northern part, rich in chlorophyll-*a*, and a southern part where the lowest chlorophyll-*a* values were recorded.

In spring 2016, concentrations of chlorophyll-*a* increased following an inshore-offshore gradient across the bay (Fig. 3h).

3.2. Zooplankton community structure and distribution

A total of 14 groups of zooplankton were found during the two study periods where 11 groups were identified in autumn 2015 and 10 in spring 2016 (Table 2). Copepods dominated

Table 1 Average, minimum–maximum and standard deviation (Std) values of the surface environmental parameters in Cintra Bay, and MANOVA test between periods.

Parameters	2015		2016		p
	Average (min–max)	Std	Average (min–max)	Std	
Temperature [°C]	21.8 (19.7–23.7)	1.0	20.1 (18.6–21.8)	1.0	***
Salinity [psu]	36.8 (36.2–37.7)	0.4	36.5 (36.4–36.7)	0.1	*
Nitrate [μM]	2.0 (0.14–6)	2.1	2.6 (0.67–5.45)	1.3	ns
Nitrite [μM]	0.6 (0.18–1.40)	0.4	0.3 (0.10–1.19)	0.3	ns
Phosphate [μM]	0.6 (0.28–1.69)	0.4	0.30 (0.10–0.47)	0.1	*
Silicate [μM]	0.2 (0.1–0.27)	0.1	0.20 (0.10–0.24)	0.04	ns
Dissolved oxygen [mg l^{-1}]	6.6 (5.25–8.5)	1.0	5.9 (5.17–7.11)	0.5	ns
Chlorophyll- <i>a</i> [$\mu\text{g l}^{-1}$]	2.7 (0.85–4.57)	1.4	0.2 (0.10–0.39)	0.1	***

* Significance level: $p < 0.05$.*** Significance level: $p < 0.001$.ns – $p \geq 0.05$ indicates not significant.**Table 2** Zooplankton groups abundance (Ab) (mean \pm standard deviation) [ind m^{-3}] and frequency of occurrence (Occ) [%] in Cintra Bay, in autumn 2015 and spring 2016.

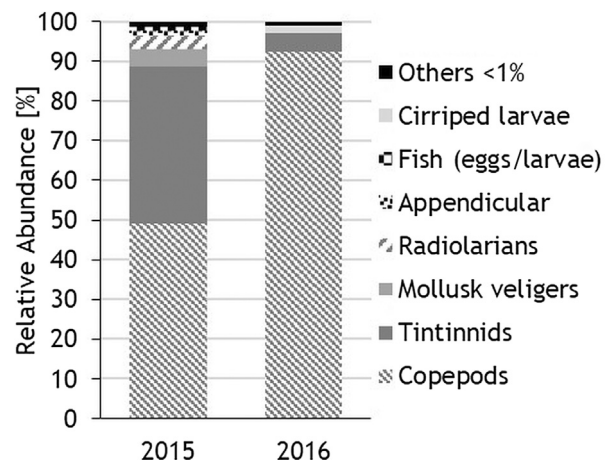
Taxa	2015		2016	
	Ab	Occ	Ab	Occ
Annelid larvae	15.1 \pm 58	46.2	0.012 \pm 0.04	7.7
Appendicular	44.6 \pm 63	53.8	0.048 \pm 0.7	7.7
Chaetognaths	15.2 \pm 32	38.5	0.012 \pm 0.4	7.7
Cirriped larvae			2.62 \pm 5	38.5
Cladocerans	17.1 \pm 34	53.8	1.19 \pm 2	53.8
Copepods	2292.6 \pm 1857	100	151.1 \pm 243	84.6
Decapod larvae		38.5		
Fish (eggs/larvae)	39.6 \pm 68	61.5	0.03 \pm 0.1	15.4
Foraminifera			0.10 \pm 0.3	15.4
Mollusk veligers	159.8 \pm 319	69.2	1 \pm 1.14	30.8
Mysidacea	0.20 \pm 1	7.7		
Ostracods	0.84 \pm 1	30.8		
Radiolarians	104.7 \pm 251	23.1		
Tintinnids	1612.5 \pm 2060	100	7.6 \pm 14	38.5

zooplankton abundance in both surveys, representing 49.1% in the autumn and 92.5% in the spring. The tintinnids were the second most abundant group with 39.7% of total abundance in autumn 2015 and only 4.7% in spring 2016.

Overall, the other groups were not abundant (<1%) and mainly represented by mollusk veligers, radiolarians, appendicular and fish in 2016, and mainly of cirriped larvae in 2015 (Fig. 4). In autumn 2015, fish eggs were collected in relatively high abundance (516 eggs m^{-3}), indicating that Cintra Bay was a favorable area for fish spawning in this period.

The total zooplankton abundance was higher in autumn 2015 (55 992 ind m^{-3}) than in spring 2016 (2123 ind m^{-3}) and the difference was highly significant ($p < 0.001$).

The spatial distribution of copepods abundance in autumn 2015 did not show any clear distribution pattern. The abundances recorded in most stations were high and exceeded 1000 ind m^{-3} . The highest value was observed at station 5 (5948 ind m^{-3}), where the offshore water masses enter the bay, while the lowest abundance (79 ind m^{-3}) was recorded

**Figure 4** Relative abundance of zooplankton groups identified in Cintra Bay in autumn 2015 and spring 2016.

near the coast at station 8 (Fig. 5a). Spring 2016 was marked by a quasi-absence of zooplankton, and therefore of copepods, in the extreme northern part of the bay (stations 1, 2, 3 and 4) where only one specimen was recorded at each station 2 and 4. Generally low in this season (maximum: 859 ind m⁻³), the abundance of copepods was higher in the transect located at the Bay opening than along the central and coastal transects.

Tintinnids showed a highly significant difference in abundance between the two periods ($p < 0.01$). Indeed, the total abundance was very high in autumn 2015 (20 963 ind m⁻³) with a wide spatial distribution throughout the bay. The maximum abundance was recorded at station 11 (6906 ind m⁻³) and the minimum, as it was the case for copepods, at station 8 (27 ind m⁻³). In spring 2016, the spatial distribution of tintinnids was limited to a few stations whose maximum abundance (47 ind m⁻³) was recorded in station 5 and the minimum (6 ind m⁻³) in station 8 (Fig. 5b).

The larval stages of copepods, particularly the nauplii, were relatively abundant and accounted for 19 and 29.5% of the total copepods respectively in autumn 2015 and spring 2016. The copepodite stage only represented 1 and 2.3%, respectively. A total of 19 species of adult copepods, belong-

ing to 14 families, were identified in Cintra Bay with 15 species found in autumn 2015 and 12 in spring 2016 (Table 3).

In autumn 2015 the copepod community was dominated by *Euterpina acutifrons* (39.3% of total adult copepods), distributed throughout the bay (100% occurrence) with a total abundance of 9836 ind m⁻³. The Acartiidae family was represented by three species (*Acartia clausi*, *A. tonsa* and *A. bifilosa*) occupying the second position (34% of total adult copepods) with a total abundance of 8392 ind m⁻³. *Paracalanus parvus*, *Oithona nana* and *Clausocalanus arcuicornis* were also abundant and widely distributed.

In spring 2016, the most abundant species of copepods were *O. nana* and *E. acutifrons*, with 54.4 and 27.7%, respectively and were distributed throughout the bay except in the northern part where copepods were almost absent. The only species of Acartiidae identified (*A. clausi*), displayed a wide distribution despite its low abundance (99 ind m⁻³), that accounted for 7.4% of total adult copepods.

Specimens of the genus *Tigriopus* were present in low numbers (total abundance 11.3 ind m⁻³ in autumn 2015 and 0.63 ind m⁻³ in spring 2016) and were located mainly in the northern part of the bay. Species of this genus had not been previously reported on the Moroccan coast.

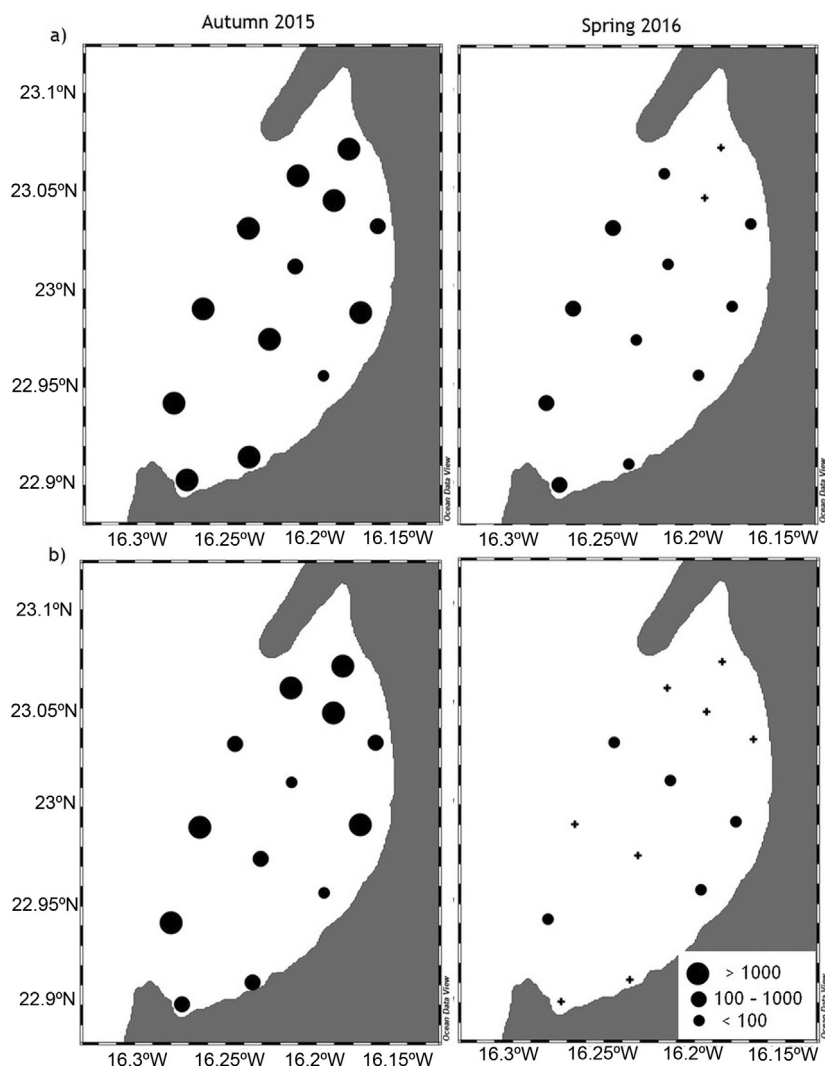


Figure 5 Spatial distribution of total copepods (a) and tintinnids (b) abundances [ind m⁻³].

Table 3 Species abundance of adult copepods (Ab) (mean \pm standard deviation) [ind m^{-3}] and frequency of occurrence (Occ) [%] in Cintra Bay in autumn 2015 and spring 2016.

Families	Species	Code	2015		2016	
			Ab	Occ	Ab	Occ
Acartiidae	<i>Acartia biflosa</i> (Giesbrecht, 1881)	Aca bif	35.6 \pm 56	46.2		
	<i>Acartia clausi</i> Giesbrecht, 1889	Aca cla	393.7 \pm 697	92.3	7.63 \pm 12	69.2
	<i>Acartia tonsa</i> Dana, 1848	Aca ton	216 \pm 282	92.3		
Calanidae	<i>Calanus helgolandicus</i> (Claus, 1863)	Cal hel	3.3 \pm 8	15.4		
	<i>Nanocalanus minor</i> (Claus, 1863)	Nan min	2 \pm 7	7.7		
Calocalanidae	<i>Calocalanus styliremis</i> Giesbrecht, 1888	Calo sty	2.2 \pm 6	15.4		
Centropagidae	<i>Centropages typicus</i> Krøyer, 1849	Cen typ	3.01 \pm 4	7.7	0.38 \pm 1	7.7
Clausocalanidae	<i>Clausocalanus arcuicornis</i> (Dana, 1849)	Cla arc	100.9 \pm 174	61.5	0.24 \pm 1	7.7
Corycaeidae	<i>Ditrichocorycaeus anglicus</i> (Lubbock, 1857)	Dit ang	0.08 \pm 031	76.9		
Eucalanidae	<i>Eucalanus elongatus</i> (Dana, 1848)	Euc elo			3.19 \pm 11	15.4
Tachydiidae	<i>Euterpina acutifrons</i> (Dana, 1847)	Eut acu	756.6 \pm 822	100	28.5 \pm 41	84.6
Ectinosamatidae	<i>Microsetella rosea</i> (Dana, 1847)	Mic ros			0.14 \pm 0.43	69.2
Oithonidae	<i>Oithona similis</i> (Claus, 1863)	Oit sim			0.19 \pm 1	7.7
	<i>Oithona nana</i> Giesbrecht, 1891	Oit nan	122.3 \pm 93	100	56 \pm 116	15.4
Oncaeidae	<i>Oncaea venusta</i> Philippi, 1843	Onc ven	1.75 \pm 6	7.7	1.54 \pm 5	46.2
Paracalanidae	<i>Paracalanus parvus</i> (Claus, 1863)	Par par	206 \pm 376	92.3	5.03 \pm 14	15.4
Temoridae	<i>Temora longicornis</i> (Muller, 1792)	Tem lon	0.24 \pm 1	7.7		
	<i>Temora stylifera</i> (Dana, 1849)	Tem sty			0.048 \pm 0.17	7.7
Harpacticidae	<i>Tigriopus</i> sp.	Tri sp.	0.86 \pm 2	15.4	0.048 \pm 0.17	7.7

Copepod diversity indices differ significantly between the two seasons ($p < 0.05$ for H' and $p < 0.01$ for S). In autumn 2015, H' varied between 0.71 and 2.75 with high copepods diversity at the stations located at the opening and the center of the bay. Species richness was also high in the center of the bay. In the northern and southern parts of the bay, both H' and S were low.

In spring 2016, the copepod community was more diversified in the southern part of the bay where values of H' were greater than 1 (maximum 2.90). In the northern part, only the stations close to the entrance of offshore waters (stations 5 and 6) showed a high diversity (Fig. 6).

According to the indicator species analysis (*IndVal*) (Table 4), different copepod assemblages characterized seasons. In autumn 2015, among the 13 species of copepods that characterized this period, seven contributed significantly to this assemblage ($\text{IndVal} \geq 25\%$ and $p < 0.05$). In contrast, only four species have been associated with the spring season but their contribution were not significant.

The results of the CCA, revealed a significant correlation between zooplankton groups and the environment (Monte Carlo Permutation Test; $p = 0.001$) for the first two axes ($F1 = 0.868$ and $F2 = 0.835$). The cumulative percent of variance for these two axes was 67.6%. Temperature was strongly and positively correlated with the $F1$ axis ($r = +0.739$) and chlorophyll-*a* with the $F2$ axis ($r = +0.707$). Salinity contributed the least in the ordination of zooplankton groups.

The projection of zooplankton groups into the factorial biplot $F1 \times F2$ showed a few distinct groups linked to extreme values of the environmental parameters. For instance, radiolarians, positively correlated with temperature (Spearman's

$r = 0.24$, $p = 0.01$) were collected only in autumn 2015, mainly in the southern area at higher temperatures. On the contrary, cirriped larvae found in spring 2016 were significantly correlated with low values of temperature, nitrites and chlorophyll-*a* (Spearman's $r = 0.26$, $p = 0.008$; $r = 0.18$, $p = 0.03$ and $r = 0.20$, $p < 0.0001$, respectively). Although the foraminifera form a distinct group, they did not show any significant correlation with environmental parameters, probably due to their low abundance and their presence limited to the spring 2016 (Fig. 7).

Copepods and tintinnids, the two dominant groups of zooplankton, were strongly correlated with chlorophyll-*a* (Spearman's $r = 0.51$ and $r = 0.56$, $p < 0.0001$), and moderately with temperature and phosphates (Spearman's $r = 0.25$, $p = 0.01$ and $r = 0.21$, $p = 0.02$, respectively).

The CCA carried out only with copepod species and environmental factors showed a strong significant correlation (Monte Carlo Permutation Test; $p = 0.001$) for first two axes (0.934 and 0.835, respectively, for $F1$ and $F2$) that explained 63.6% of the variance. Chlorophyll-*a*, temperature and dissolved oxygen contributed negatively to $F1$ axis with medium coefficients of correlation ($r = -0.667$, $r = -0.542$ and $r = -0.407$ respectively) in addition to silicates on the opposite side ($r = +0.479$). Salinity was the most positively correlated factor with the $F2$ axis ($r = +0.576$) in addition to temperature and phosphates ($r = +0.423$ and $r = +0.409$, respectively).

The $F1 \times F2$ biplot indicated that some copepod species, identified in either season, and showing a limited distribution along the bay, form distinct groups. On the positive side of the $F1$ axis, *Oithona similis*, *Eucalanus elongatus* and *Temora stylifera*, found only in spring 2016 and located in the

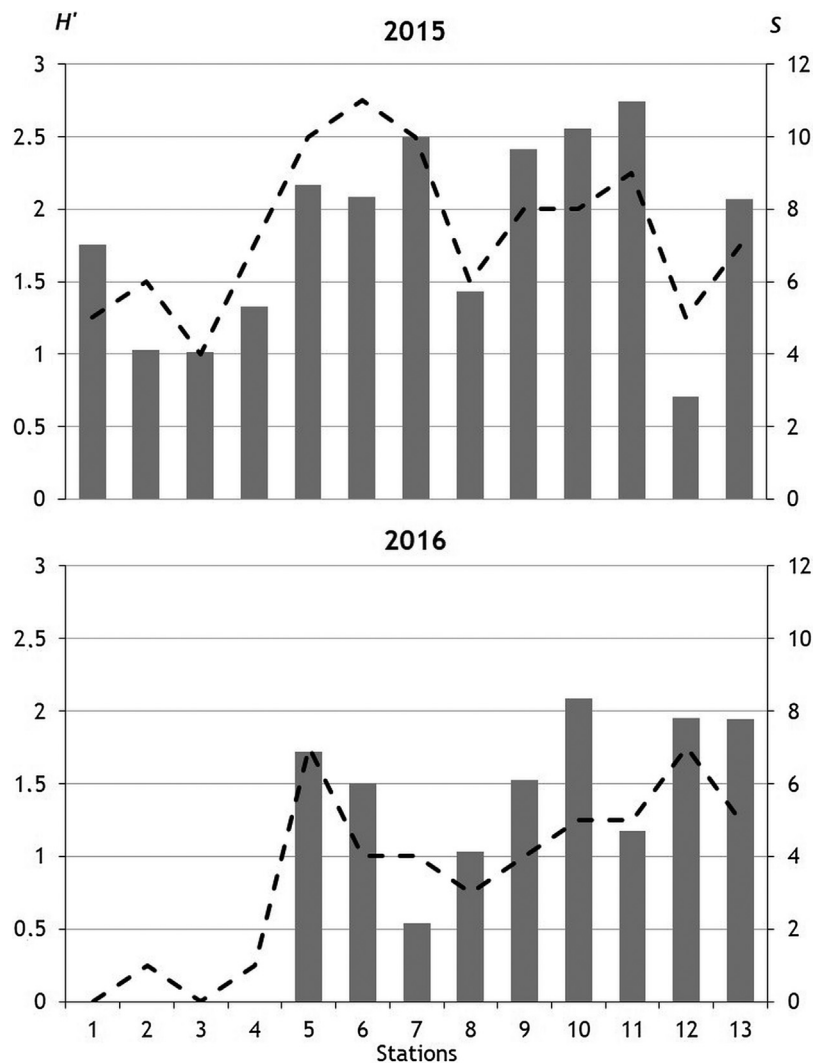


Figure 6 Spatial and temporal variations of Shannon-Wiener index (H') (histograms) and species richness (S) (lines) in Cintra Bay during the two survey periods.

extreme southern part of the bay, showed no significant correlation with the environmental parameters. On the opposite side of the axis, the species *Calanus helgolandicus* and *Calocalanus styliremis*, found only in autumn 2015 and located mainly at stations 5 and 6, at the entrance of the bay, were correlated with salinity and silicates (Spearman's $r = 2.22$, $p = 0.02$ and $r = 0.16$, $p = 0.04$, respectively, for both species). Moreover, *Ditrichocorycaeus anglicus*, positioned on the same side of the axis, and *Oncaea venusta* in the middle, showed no correlation with environmental parameters, probably due to their low abundances (Fig. 8).

Despite its limited spatial distribution, *Tigriopus* sp., showed a significant correlation with nitrates (Spearman's $r = 0.19$, $p = 0.03$) and seemed to present a wide tolerance for variations in other parameters. The three species of Acartiidae have differential behavior with respect to some of the environmental parameters considered. Indeed, chlorophyll-*a* and temperature were the two factors that were significantly involved in distribution and abundance of *A. tonsa* (Spearman's $r = 0.57$, $p < 0.0001$ and $r = 0.35$, $p = 0.002$, respectively), dissolved oxygen and nitrates for

A. biflosa (Spearman's $r = 0.16$, $p = 0.04$ and $r = 0.15$, $p = 0.04$, respectively) and only chlorophyll-*a* for *A. clausi* (Spearman's $r = 0.18$, $p = 0.03$).

4. Discussion

Cintra Bay has a great potential for the development of aquaculture, given its geographical positioning in a part of Northwest Africa (21–26°N) that is characterized by a permanent upwelling, generating a high productivity and a high abundance of fishery resources. Given its orientation along the NW-SW axis, and its communication with the Atlantic Ocean through its wide opening, the environmental parameters in the Cintra Bay denote the influence of the offshore environment, which is more pronounced at the entrance and in the center of the bay. Indeed, the entrance and the central part of the bay were invaded by waters coming from the open ocean and therefore were cooler, less salty and rich in nutrients. Near to the coast, the shallow depth and the absence of freshwater input resulted in high values for

Table 4 Copepod indicator species for each period based on indicator values (IndVal $\geq 25\%$) and their significant contribution ($p < 0.05$).

Period	Species	IndVal	p
2015	<i>Euterpina acutifrons</i>	98.1	***
	<i>Acartia tonsa</i>	96.1	***
	<i>Acartia clausi</i>	95.1	**
	<i>Paracalanus parvus</i>	95.1	**
	<i>Clausocalanus arcuicornis</i>	87.6	***
	<i>Centropage typicus</i>	73.7	**
	<i>Acartia bifilosa</i>	67.9	*
	<i>Calanus helgolandicus</i>	39.2	ns
	<i>Calocalanus styliremis</i>	39.2	ns
	<i>Tigriopus</i> sp.	38.2	ns
	<i>Ditrichocorycaeus anglicus</i>	27.7	ns
	<i>Nanocalanus minor</i>	27.7	ns
	<i>Temora longicornis</i>	27.7	ns
2016	<i>Eucalanus elongatus</i>	39.2	ns
	<i>Microsetella rosea</i>	39.2	ns
	<i>Oithona similis</i>	27.7	ns
	<i>Temora stylifera</i>	27.7	ns

* Signif. code: $p < 0.05$.

** Signif. code: $p < 0.01$.

*** Signif. code: $p < 0.001$.

ns – $p \geq 0.05$ indicates not significant.

temperature and salinity and low values for nutrients. The high variability in environmental parameters between the two study periods, particularly temperature, chlorophyll-*a* concentration and phosphates, is related to the intensity of the upwelling in the adjacent marine environment (21–26°N). This upwelling has a low seasonality, a maximum

intensity in autumn and a pronounced interannual variability (Benazzouz et al., 2014, 2015; Cropper et al., 2014).

As a confluence of inland and marine waters, the paralic systems are among the most fluctuating and productive ecosystems in the world (Etilé et al., 2015). These paralic systems are subject to internal and irregular variations, due to intrinsic characteristics (shallowness, continuous dissolved and particulate matter input) and external energy generating internal dynamics, which modulate their biocenosis (Brugnano et al., 2011; Etilé et al., 2009). Several studies have been conducted in a multitude of coastal ecosystems and have demonstrated the strong correlation between habitat conditions of these ecosystems and the abundance and structure of zooplankton communities (Abdul et al., 2016; Anton-Pardo and Armengol, 2012; Badsì et al., 2010; Dube et al., 2010; Etilé et al., 2009; Gao et al., 2008; Gozdziejewska and Karpowicz, 2013; Gutkowska et al., 2018; Joyce et al., 2005; Paturej and Kruk, 2011; Paturej and Gutkowska, 2015; Paturej et al., 2017; Zakaria et al., 2007).

Except for copepods and tintinnids, the autumn season was characterized by relatively high abundances of different zooplankton groups in Cintra Bay, particularly radiolarians, appendicular, cirriped larvae and early life stages of fish. In autumn 2015, exclusively fish eggs represented the latter group; while in spring 2016, fish eggs and larvae were almost absent. According to a simulation model and in situ observations of ichthyoplankton along 32–21°N region, high coastal retention rates were obtained from Cape Bojador to Cape Blanc (26–21°N), which includes Cintra Bay, especially in autumn and winter (Berraho, 2007; Brochier et al., 2008). This region is known for its great richness in fish resources, mainly the sardine whose main spawning takes place in autumn. Furthermore, the concave configuration of the Cintra Bay and its wide opening to the sea promote retention of coastal waters and consequently planktonic organisms whose

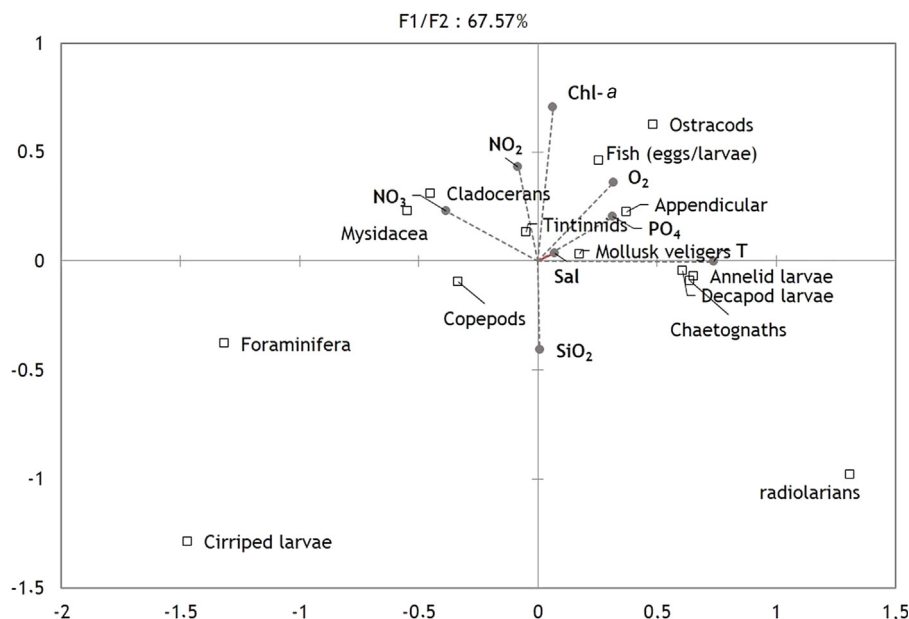


Figure 7 Canonical Correspondence Analysis (CCA) ordination plot for zooplankton groups and environmental variables of the surface layer (T: temperature; Sal: salinity; NO₃: nitrates, NO₂: nitrites; PO₄: phosphates; SiO₂: silicates; O₂: dissolved oxygen; Chl-*a*: chlorophyll-*a*).

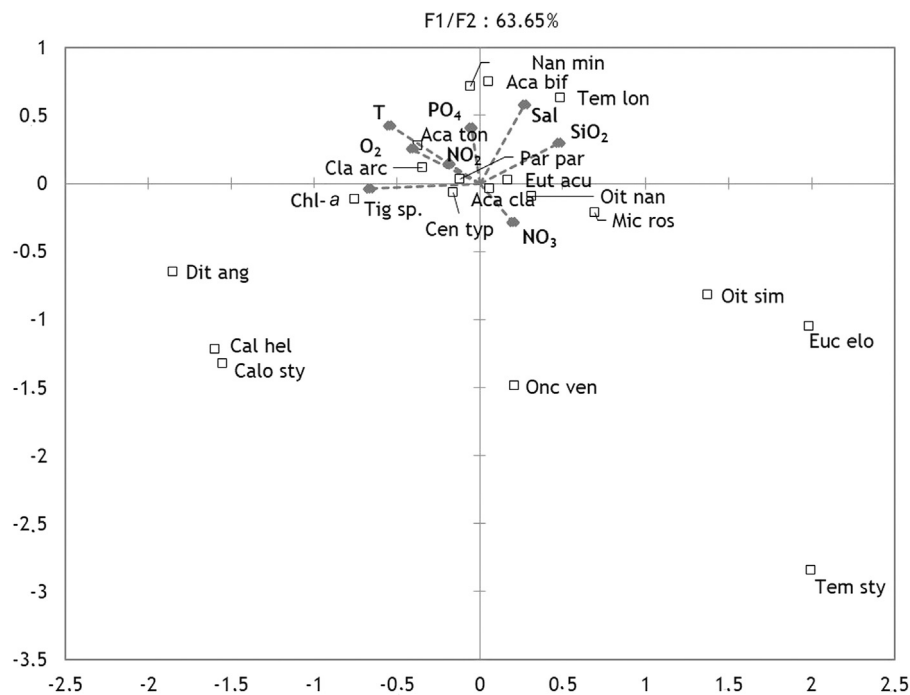


Figure 8 Canonical Correspondence Analysis (CCA) ordination plot for copepod species and environmental variables of the surface layer (T: temperature; Sal: salinity; NO₃: nitrates, NO₂: nitrites; PO₄: phosphates; SiO₂: silicates; O₂: dissolved oxygen; Chl-a: chlorophyll-a). Code for copepod species in Table 3.

abundance and diversity are related to the seasonal variability of environmental conditions and species life cycles.

If copepods are the key component of mesozooplankton, tintinnids are the key for microzooplankton. Tintinnids play a crucial role in transferring elements and energy from low trophic levels (pico- and nano-phytoplankton) to high one such as copepods and fish larvae (Crawford et al., 1997; Dolan, 2010; Stoecker, 2013) and they are considered to be bio-indicators for some environmental factors (El-Damhougy et al., 2017). According to Chaudhary et al. (2016), they display the most common global biogeographic pattern found among marine species, illustrated by the bimodal diversity gradient, wherein species richness increases from high to low latitudes with a slight dip near the equator. In Cintra Bay, tintinnids had a strong presence in autumn 2015, compared to the spring 2016. This seasonal variation could be attributed to the seasonality of upwelling, which generates a high nutrient and phytoplankton richness in the coastal zone in autumn. Indeed, the presence of tintinnids was strongly correlated with chlorophyll-*a*, temperature and phosphates. Recent studies revealed that chlorophyll-*a* and nutrients were the potential significant factors influencing the tintinnid abundance and distribution in coastal zones (Dash et al., 2017; Rakshit et al., 2016; Wang et al., 2014). In addition, Dolan et al. (2002) conclude that tintinnid diversity, both morphological and taxonomic, is more closely linked to phytoplankton diversity in terms of cell sizes, than competitive interactions or predation.

The copepod group was dominant in Cintra Bay, and showed a strong seasonal variability of abundance with a relatively high presence of larval stages (nauplii) particularly in spring. Taking into account the mesh size of the used net

(150 μ m), these larval proportions are probably underestimated but still indicate seasonal variability. According to Makabe et al. (2012), no significant underestimation of copepod abundance was found using the 100 μ m mesh, except for copepod nauplii that should be quantified using a finer mesh size, such as 60 μ m (Nichols and Thompson, 1991). However, despite the use of a mesh size 44 μ m, Emir Akbulut and Tavşanoğlu (2018) found no seasonality for nauplii but did find a seasonality for different life stages of copepod in relation to the variation of temperature and salinity. Several authors have highlighted the influence of local hydrographic factors and their seasonal and inter-annual variability in coastal zooplankton dynamics, including copepods in the Mediterranean Sea (Berline et al., 2012; Beşiktepe et al., 2015; Fernandez de Puelles et al., 2003; Gaudy and Champalbert, 1998; Krsinic et al., 2007; Molinero et al., 2008; Siokou-Frangou, 1996; Uysal and Shmeleva, 2012). In upwelling systems, the life cycle of copepods is multigenerational (up to 10 generations or more each year) depending upon water temperature, food concentration and length of the upwelling season (Peterson, 1998). Different strategies (diapause, resting phase, diel vertical migration) can be adopted by the species according to each upwelling system such as the case of *Calanoides carinatus* in the southern Benguela ecosystem where upwelling is not restricted to the main upwelling season (6–8 month), but it also takes place occasionally during winter (Verheye et al., 1991). In the permanent upwelling along the African region 19–24°N, the SeaWiFS data analysis showed a high primary production throughout the year with a minimum and a maximum production detected, respectively, in December and in April–May (Demarcq and Somoue, 2015; Lathuilière et al., 2008).

This situation can lead to a seasonality of the different life stages of the copepods including the nauplius stage. In Oualidia lagoon (Moroccan Atlantic coast), the nauplii was prevalent in the system throughout the whole year with a large seasonal variation characterized by very low densities in winter (Ouldessaib et al., 1998).

The structure of the copepod community along the Cintra Bay was dominated by neritic marine species, characterized by high spatial and seasonal variability of their abundances. In autumn 2015, *E. acutifrons* and three species of Acartiidae (*A. clausi*, *A. tonsa* and *A. bifilosa*) accounted for the majority of adult copepods while in spring 2016, *O. nana* largely dominated the copepod community. In the spring, *A. clausi* species was the only representative of Acartiidae with low abundance but with a wide spatial distribution in both seasons. Generally, marine forms of copepod communities, whose structure depends on the environmental characteristics of each site and the sampling period, dominated in different areas along the Moroccan Atlantic coast (Ait-talborjt et al., 2016; Badsı et al., 2010; Ouldessaib et al., 1998; Youssara et al., 2004). The coexistence of several congeneric species of *Acartia* is particularly linked to variations in temperature and salinity (Brugnano et al., 2011; Conover, 1956; Gutkowska et al., 2018; Herman et al., 1968; Paturej and Kruk, 2011; Paturej and Gutkowska et al., 2015; Peck et al., 2015; Sage and Herman, 1972). Along the north-western African coast, *A. clausi* is reported as a common species in marine and coastal areas cohabiting with other congeners (Ait-Talborjet et al., 2016; Berraho et al., 2016; Boucher, 1982; El Khalki and Moncef, 2007; Ndour et al., 2018; Ouldessaib et al., 1998; Salah, 2013; Somoue et al., 2005; Youssara et al., 2004; Zaafa et al., 2012). Furthermore, *A. tonsa* was mentioned only recently (in 1990s) in the marine environment, between Cape Bojador and Cape Blanc (26–21°N) (Somoue et al., 2005; Zizah et al., 2012) and currently in Dakhla Bay (24°N) (Berraho et al., 2018). However, *A. bifilosa* was not previously listed in copepod community studies on the Moroccan coast, although its presence is mentioned in this region by Razouls et al. (2005–2018). According to Ruiz et al. (1997), the occurrence of invasive species of zooplankton is increasing at an alarming rate in marine and estuarine systems and it is often associated with ship ballast waters or release by aquaculture, fisheries or pet industries. It is the case of *A. tonsa*, which appeared in Europe in the first half of the 20th century and progressively colonized European seas and estuaries. The species was possibly introduced from the northern Atlantic coast of America (Chaalali et al., 2013; David et al., 2007). Similarly, recent studies have reported the presence of this species in brackish Nigerian waters (southern West Africa) (Nkwoji et al., 2010; Wokoma, 2016), probably due to the same cause. In contrast, since its description by Giesbrecht (1881) from samples collected at Kiel (Germany), *A. bifilosa* has been reported as an autochthonous species from temperate and North Atlantic, characteristic of brackish and estuarine systems (Hirst and Castro-Longoria, 1998). There is no monitoring of planktonic communities in coastal areas of northwest Africa, and therefore it is impossible to state the origin and date the appearance of some species. This is the case of Cintra Bay, where this first inventory of copepod species allowed the identification of a species of the genus *Tigriopus*, not previously mentioned in the Northwest African

region. This genus is reported to be highly speciose and generally restricted to high intertidal and supralittoral rock pools worldwide that are naturally fragmented with low connectivity among populations (Altermatt et al., 2012; Davenport et al., 1997). The northern tip of the bay is a flood-prone peninsula extending for 2 miles to the southwest and ending in sandy rocks and a natural reef. It protects the entire northern extremity of the bay, characterized by shallower depths (less than 5 m) and low marine hydrodynamic (Hilmi et al., 2017; Makaoui et al., 2017). All these characteristics are probably favorable for the population development of *Tigriopus* sp., which must be confirmed by further studies.

Cintra Bay is largely open to the Atlantic Ocean, which provides abiotic and biotic characteristics largely influenced by the upwelling and the general circulation of the offshore water masses, which explains the high spatial and temporal variability of temperature and chlorophyll-*a*. This also implies a variability in the structure and abundance of zooplankton, illustrated particularly by the high variability of copepod diversity indices (H' and S) which showed a clear separation between the open part and the coastal part of the Bay. In addition, the CCA results highlighted the significant role of temperature and chlorophyll-*a* in structuring zooplankton communities and particularly the dominant groups: copepods and tintinnids. Generally, the main spatial and seasonal gradients of zooplankton were associated with temperature and food availability (Benítez-Díaz Mirón et al., 2014; Tackx et al., 2004; Terbiyik Kurt and Polat, 2015). This is the case of radiolarians, located mainly in the southern part of Cintra Bay, at high water temperatures, and cirriped larvae, significantly correlated with low water temperatures. The involvement of other environmental factors in structuring the zooplankton community and abundance is related to the margin variation of each parameter, the taxon tolerance margins and the taxonomic scale considered. In Cintra Bay, salinity contributed the least to the ordination of zooplankton but was a strong contributing factor for some copepod species with other factors. However, salinity has been found to be a major structuring factor in the composition and distribution of zooplankton taxa in coastal areas subjected to the freshwater input and/or anthropogenic activities (Benítez-Díaz Mirón et al., 2014; Bruçet et al., 2009; Etilé et al., 2009; Montoya-Maya and Strydom, 2009; Nkwoji et al., 2010; Prado et al., 2017). This is likely to increase further in light of global-warming (Bruçet et al., 2010). The salinity range recorded during both study periods in Cintra Bay (36.2–37.7 psu) indicated a high influence of open ocean waters and relatively low variability and hence, exerted a negligible effect in structuring zooplankton.

According to the indicator species analysis, the copepod structure was characterized by a wide diversity in autumn, with *E. acutifrons*, *P. parvus*, *C. arcuicornis*, *C. typicus* and the three species of Acartiidae (*A. clausi*, *A. tonsa* and *A. bifilosa*) contributing significantly to this structure. The CCA analysis showed a wide tolerance of these species to the environmental parameters with a highly significant correlation with chlorophyll-*a*. However, the three species of Acartiidae had a differential behavior with respect to some environmental parameters. *A. clausi* is a perennial species with a succession of peak abundances, whose amplitude varies during an annual cycle (Ouldessaib et al., 1998; Youssara et al., 2004). This

succession is linked to food availability that could act as a limiting factor and determine the duration of each or any stage and hence affect the total generation length (Christou and Verriopoulos, 1993). *Acartia tonsa* and *A. bifilosa* were reported as a summer-autumn species in Mediterranean lagoons and many North European estuaries (Brugnano et al., 2011; David et al., 2007; Uriarte and Villate, 2005). They are able to produce resting eggs under unfavorable conditions (Castro-Longoria, 2003; Katajisto, 2003; Peck et al., 2015).

The indicator species analysis highlighted the species poorly represented and only recorded in the spring (*E. elongatus*, *M. rosea*, *O. similis* and *T. stylifera*), showing no significant correlation with environmental parameters. These four species, whose abundance is widely fluctuating, have been reported in both offshore and coastal waters of the Atlantic coast of Morocco. *T. stylifera* and *O. similis* are the most commonly encountered throughout the year, with high abundances in spring and autumn-winter, respectively, whereas the presence of *E. elongatus* and *M. rosea* is generally sporadic (Ouldessaib et al., 1998; Somoue et al., 2005; Youssara et al., 2004; Zizah et al., 2012). The succession of species displays different spatial and/or seasonal patterns, suggesting differences in their ecological traits (Beşiktepe et al., 2015; Siokou-Frangou et al., 2010).

In conclusion, this study showed that the structure and abundance of zooplankton taxa in Cintra Bay is closely related to the environmental conditions that were mainly driven by the bay configuration and the regional hydrodynamics, particularly the upwelling, which was more intense in autumn. This coastal ecosystem could host different activities (aquaculture, industry, tourism, etc.), the implementation of which requires knowledge of the abiotic and biotic components and their spatio-temporal variations. In addition, Cintra Bay is part of a large marine area considered to be a spawning ground for fish species, particularly sardine, which is the dominant species of the Moroccan pelagic fishery. Thus, this study is a first step toward better knowledge of the planktonic biodiversity in this region.

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