



Diel Variation of Zooplankton Community Composition, Abundance and Biomass in a West African Tropical Coastal Lagoon (Grand-Lahou, Côte d'Ivoire)

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Abstract – The short-term dynamics (circadian and tidal cycles) of the zooplankton community were investigated in the Grand-Lahou lagoon. The plankton samples were collected in March-April (dry season) at 3 stations, every 4 hours over a 24-hour period. Altogether, Forty one zooplankton taxa were identified, of which *Oithona brevicornis* (4 to 99 ind.l⁻¹; mean : 33 ind. l⁻¹; 61% total zooplankton abundance) was the dominant species. Significant short-term variation was observed in total zooplankton and main species abundance and biomass. Generally, total zooplankton and main species biomass fluctuations related to day phase. Mean total zooplankton biomass varied from 7.29 µgC.l⁻¹ (day time) to 38.54 µgC.l⁻¹ (night). Fluctuations related to tidal height were recorded in the total zooplankton and tintinnid densities at stations near the channel (station 1). Mean zooplankton density were lower at ebb tide (10 to 12 ind.l⁻¹) than at flood tide (45.77 to 72.47 ind.l⁻¹). Similar short-term pattern of tintinnids density were observed at station 1.

Keywords – Tropical Coastal Lagoon, Zooplankton Short-Term Variation, Abundance, Biomass, Grand-Lahou, Côte d'Ivoire.

I. INTRODUCTION

Coastal lagoons are considered as biodiversity “hot spots” and are among the most productive ecosystems in the world. Unfortunately, they are vulnerable and undergo degradation under anthropogenic pressures, with numerous consequences on the riverine populations [1]. It is therefore necessary to protect and rationally manage these valuable coastal ecosystems.

A number of studies have used zooplankton to monitor environmental changes in coastal lagoons because its sensitivity to environmental changes induced by abiotic and biotic factors [2]. Furthermore, zooplankton plays a major role in the functioning and the productivity of aquatic ecosystems through its impact on the nutrient dynamics and its key position in the food webs. Indeed, most zooplanktonic organisms have an herbivorous detritivorous diet and exert a strong grazing impact on the phytoplankton ([3], [4-5]) and bacterioplankton [6]. They

also constitute a food source for organisms of the upper trophic levels such as planktivorous fish and carnivorous invertebrates [7].

Besides, the zooplankton populations are dependent on trophic ([8], [9]) and salinity [10] variations. This means that any modification of the composition and the functioning of the zooplanktonic community is susceptible to affect the state of the entire ecosystem. In other words, studying the structure and the variability of zooplankton communities can supply useful information for a sustainable management of sensitive ecosystems as coastal lagoon.

The patterns and processes of zooplankton spatial and temporal distribution are thus important prerequisite for ecosystem modeling and rational management of coastal lagoons in the face of climate change and increased human disturbances. Spatial heterogeneity of zooplankton is driven by abiotic and biotic forces and by the biophysical coupling [11]. Traditionally, plankton seasonality is assumed to be less prominent in low-latitude than in high-latitude environments due to the dampened fluctuations in both irradiance and temperature, but many tropical or subtropical aquatic ecosystems are sensitive to seasonal variations due to annual hydrological cycle [12]. In shallow ecosystem such as coastal lagoons, short term variations linked to diel vertical migrations (DVM) [13] and to tidal cycles (ebb - flood or spring - neap) ([14], [15]) have important consequences for the structuration of zooplankton communities and the ecological functioning.

In the Grand-Lahou lagoon, the relationships between zooplankton distribution and environmental factors were studied to test whether the indicator properties of zooplankton assemblages could be used to monitor water [16]. This study showed that the composition of zooplanktonic communities and their spatio-temporal variations were mainly controlled by salinity variations closely linked to the climatic and hydrological context, while the role of the trophic status could not be clearly evidenced. Besides, the zooplankton composition and abundance was shown to vary remarkably with the season. However, this previous study, based on monthly sampling,

could not address short-term changes (diel variation for example). To raise this insufficiency, we initiated this study of which the main objective is to investigate patterns in short-term (diel) variability of zooplankton composition, abundance and biomass in a tropical lagoon (Grand-Lahou, Côte d'Ivoire) in relation with environmental variables.

II. MATERIALS AND METHODS

The methods section comprises detailed descriptions of study area and of sampling (Zooplankton and environmental variables) and data analysis.

The Grand-Lahou lagoon (Figure 1) is a brackish lagoon situated in the south of Côte d'Ivoire, between 5°07' and 5°14' N and between 4° and 5°25' W [17].

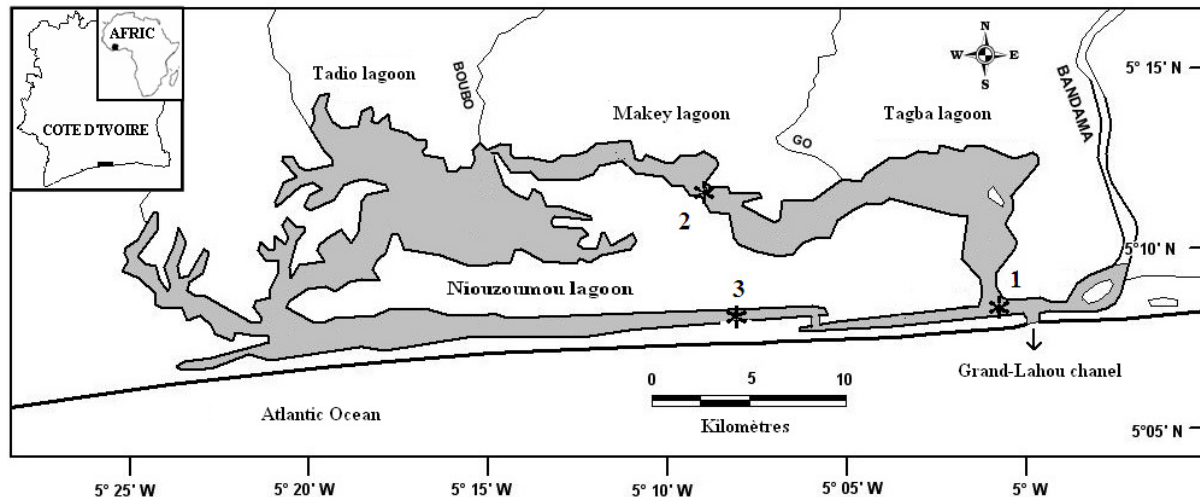


Fig.1. Localisation of the sampling station in the Grand-Lahou lagoon, Côte d'Ivoire

The main basin has an orientation East-west on 50 km, parallel to the Atlantic coast. The lagoon is a shallow basin (mean depth of 3 m; [18]) with a total area of about 190 km² [19]. It can be subdivided in two zones according to the hydroclimat ([17], [20]) : an estuarine zone located on the oriental façade regrouping the Tagba (57 km²) and Mackey (28 km²) lagoons and a western zone, composed of the Tadio (90 km²) and Niouzoumou (15 km²) lagoons. The Grand-Lahou lagoon is under the influence of oceanic and freshwaters. It has a permanent communication with the Atlantic ocean through the Grand-Lahou channel. The freshwater inputs come from two main rivers, the Boubo and the Bandama having their outlets in the Mackey and Tagba lagoons respectively.

The lagoon is situated in a region under the influence of the subequatorial climate characterized by two rainy seasons (May to July and October to November) and two dry seasons (December to April and August-September).

Zooplankton and environmental variables were recorded during the dry season from March 28 to April 2, 2006, in 3 stations (Figure 1). Station 1 (3.8 m depth) is close to the Grand-Lahou channel and is under the direct influence of the oceanic tides. Station 2 (2.3 m depth) is mainly under the influence of the Boubo river, of which the flood season is coinciding with the rainy seasons. Station 3 (4.1 m depth) is a site safe from the continental influences, with the exception of diffuse dripping waters. It is representative of the enclosed sector of the Grand-Lahou. Water level information was obtained with a relative tide scale.

The three stations were sampled successively: station 2 (28 to 29 March), station 3 (30 to 31 March) and station 1

(1st to 2 April). At each station, the sampling cycle began at 08:00 and ended the following day at 04:00 with a 4-h sampling frequency.

The physical and chemical parameters (temperature, salinity, dissolved oxygen, conductivity, turbidity and pH) were measured in surface and near the bottom, with a portable multi-parameter probe, TURO T-611. The transparency was measured using a Secchi disk. Water samples were collected with a Niskin-bottle and preserved at 4°C for subsequent analyses of nutrients [Phosphate (PO₄³⁻) and Nitrite (NO₂)] with a Technicon sensor III (Model AA3) auto-analyzer, according to protocols described by [21].

The zooplankton sampling was made using a cylindrical net (64 µm in mesh opening size, 30 cm in mouth diameter and 1 m in length) by vertical hauls from the bottom to the surface to integrate vertical variations of abundance, and to minimize effects of diel vertical migrations [22]. Samples were immediately preserved in a mixture of lagoon's water and borax neutralized formalin at a final concentration of 5%.

Zooplankton organisms were identified using the following works: [23], [24], [25]-[26]. The taxa were identified and counted under a dissecting microscope (magnification: 160, 250 and 400). The least abundant taxa were counted on the entire sample, while the most abundant taxa were counted on subsamples made with wide bore piston Eppendorf pipettes of 1 and 5 ml. One or several subsamples were examined until numbering a minimum of 100 individual per taxa, in order to minimize sub-sampling errors and to reduce the coefficient of variation to a maximum of 10% [27].

Zooplankton densities, expressed as numbers per liter (ind./L), were calculated by dividing the number of organisms estimated in each sample by the volume of water filtered in the field. The volume of filtered water obtained while multiplying the surface of the net (0.071 m²) by the depth of the site sampled (varying according to study stations). The individual weights (expressed as dry weight, DW) were estimated from their body size using the length (L in mm)-weight (DW in µg) relationship proposed by the literature ([28], [29], [30], [31]-[32]). The body size were measured under a dissecting microscope (magnification 400) using an ocular micrometer (precision ± 10 µm), on a sample of at least 30 individuals. The measures concerned specimen coming from all stations. The individual dry weights were converted into carbon (C) using a C/DW ratio = 0.045 [30].

The multivariate redundancy analysis (RDA) was carried out to determine the relationships between environmental variables and abundance of zooplankton taxa, using the Canoco-4.5 software package. The results are presented as a triplot, in which species, environmental variables and sampling hours are plotted together. One-way analyses of variance (general linear model) were performed to test the effects of hour and periods (day time and night) on zooplankton density and biomass. All calculations were performed after adequate logarithmic transformation of the data in order to obtain normal distributions. All steps of this method were computed using Statistica 7.1 software.

III. RESULTS

In this section results, we exhibit data obtained from environmental variables, zooplankton composition and diel variation, ecological index, relations between zooplankton taxa and environmental variables (multivariate analysis, RDA).

A. Environmental variables

The Grand-Lahou lagoon tides are semi-diurnal and ranged between 4 cm (low tide at station 3, 24:00) and 35 cm (high tide at stations 1 and 2 respectively at 20:00 and 16:00) (Figure 2). During our survey, the low tide occurred at 12:00 and 00:00 h at stations 1-2, and at 08:00 and 20:00 h at station 3. The high tide occurred at 08:00 and 20:00 at station 1, and at 16:00 and 04:00 at stations 2 - 3 (Figure 2).

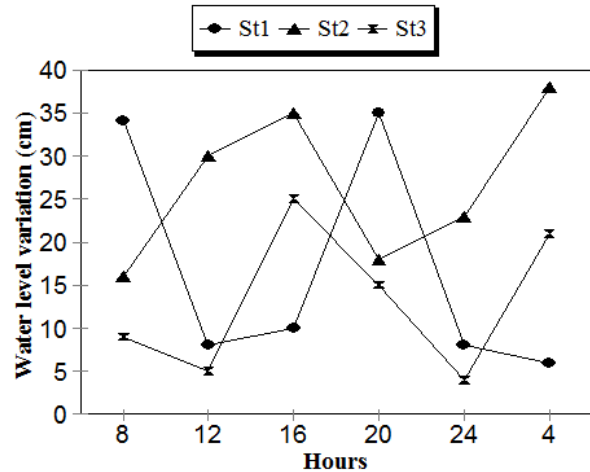
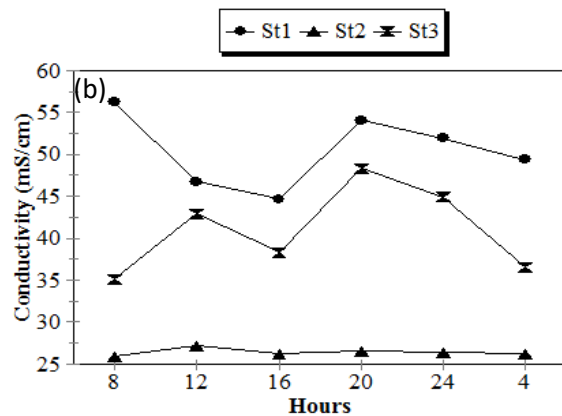
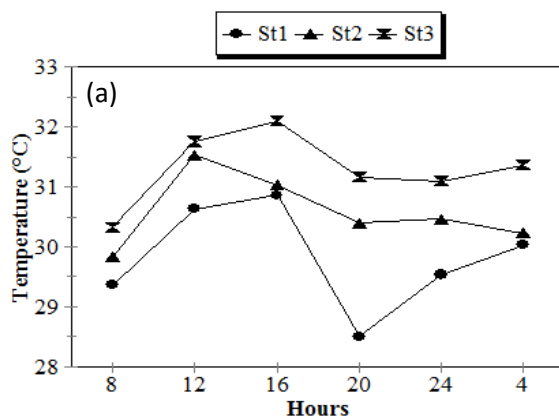


Fig.2. Diel variations of water level in Grand Lahou lagoon during 24-h sampling cycles in 3 stations.

The daily variation of the environmental variables is illustrated in Figure 3. No systematic short-term pattern in relation with circadian and tidal cycles was identified in the environmental parameter. Among the abiotic variables, only temperature varied significantly between sampling hour at all surveyed stations ($p < 0.0001$). Conductivity significantly varied between sampling hour in stations 1 and 3. Dissolved oxygen, phosphates and nitrites significantly varied respectively at stations 1, 2 and 3. Besides, no significant day phase variation was found for the physical and chemical variables (ANOVA, $p > 0.05$), with the exception of the nitrites and ammonium values at station 3 (ANOVA, $p < 0.05$).

B. Zooplankton diversity, composition and structure

Forty one zooplankton taxa were identified at all the sampling stations. These taxa are divided into four groups: Copepoda, Rotifera, Cladocera and others zooplankton. Copepoda was the most dominant group in terms of diversity (20 taxa; 48.78%), followed by the other zooplankton group (19 taxa, 45.43%) (Table I). The taxonomic richness significantly varied ($p < 0.05$) between stations and between day time and night hours. The highest taxonomic richness was recorded at station 1 (27 to 32) and the lowest at station 2 (10 to 11). The day-night difference was not significant since the taxonomic richness recorded at night was between 10 and 32 compared to that of the day from 11 to 27.



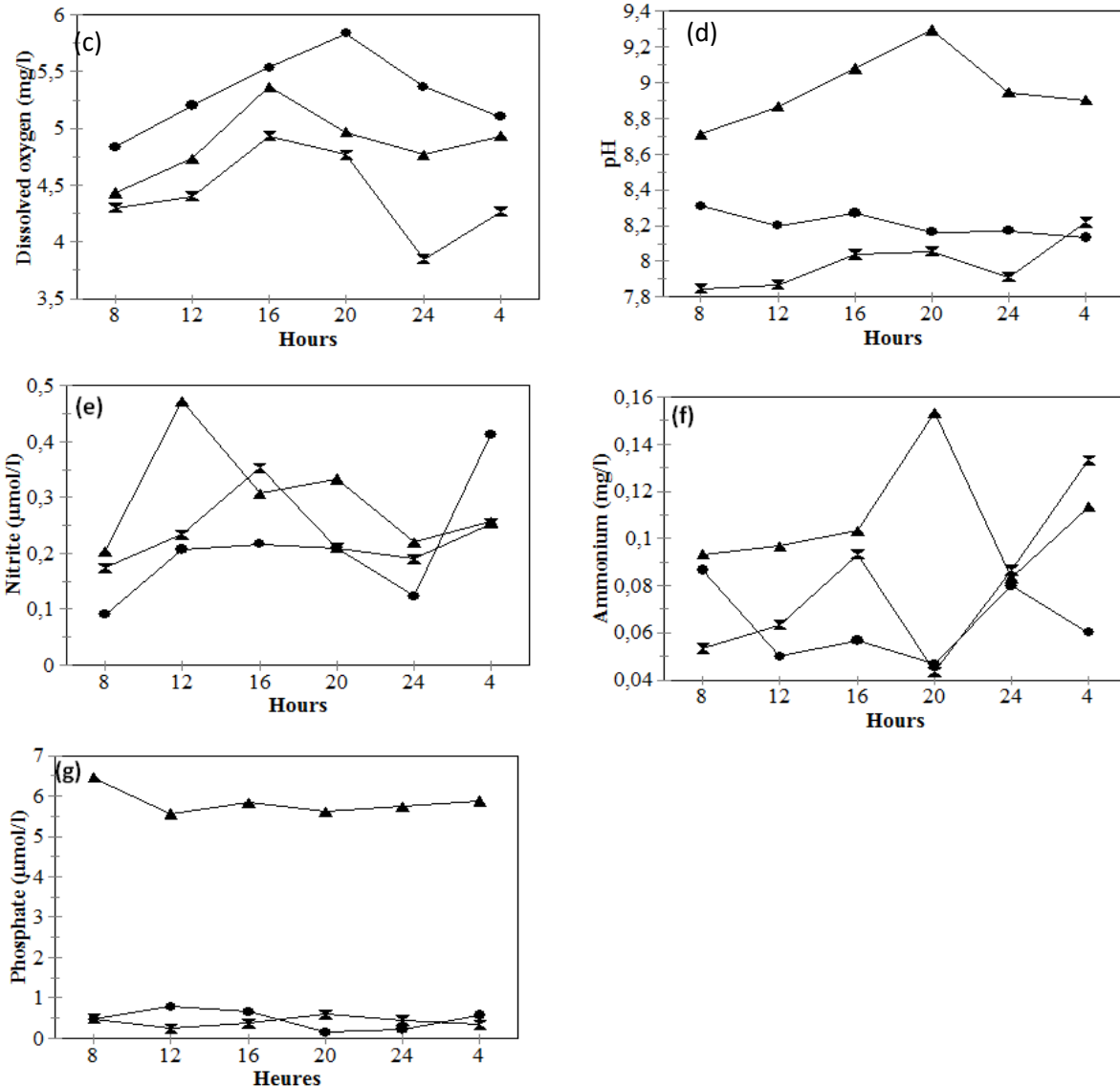


Fig.3. Diel variations of environmental variables in Grand Lahou lagoon during 24-h sampling cycles in 3 stations: (a)- Temperature, (b)-Conductivity; (c)-Dissolved oxygen; (d)-pH, (e)-Nitrites; (f)-Ammonium and (g)-Phosphates.

Mean day and night values of zooplankton abundance and biomass are shown in Table I and II respectively. The total zooplankton abundance and biomass were significantly higher at night than during the day. The total zooplankton abundance varied between 23 and 56 ind./L during the day time and between 47 and 108 ind./L at night. The total biomass varied between 6 and 10 µgC./L during the day and between 20 and 65 µgC./L at night. Copepods constituted the most dominant group in the Grand-Lahou lagoon zooplankton during both periods.

They constituted 46% to ≈ 100% (11 to 56 ind./L) of the total zooplankton density during the day and 57% to ≈ 99% (27 to 107 ind./L) of the total zooplankton density at night. Copepods biomass constituted also the most important group in samples of day time [66 to 97% of total biomass (3 to 7 µgC./L)]. In samples collected during the night, they constituted the most important group at station 3 [99% of total biomass (20 µgC./L)]; while other zooplankton group constituted the most important group

with 53 to 79% of the total biomass (16 to 52 µgC./L) at stations 2 and 3.

In terms of density, Copepods comprised 22 to 55% (3 to 19 ind./L) of nauplii and 45 to 78% (8 to 44 ind./L) of copepodid and adult stages in samples of the day and 6 to 36% (7 to 20 ind./L) of nauplii and 64 to 94% (18 to 100 ind./L) of copepodid and adult stages in samples of the night.

In terms of biomass, Copepods comprised 2 to 22% (the day) and 1 to 10% (the night) of nauplii with < 1µgC./L. So therefore, copepodid and adult stages represented the main Copepods biomass with 3 to 20 µgC./L. Copepodids and adults density included 55-98% of cyclopoids, 2-37% of calanoids and 0-8% of harpacticoids during the day. During the night, Copepodids and adults density included 73-98% of cyclopoids, 1-23% of calanoids and 0-7% of harpacticoids.

In terms of biomass, copepodid and adult stages included 16-86% of cyclopoids, 14-74% of calanoids and 1-9% of harpacticoids in samples of day and 20-86% of

cyclopoids, 8-74% of calanoids and 0-6% of harpacticoids in samples of night. So, in the both variables, cyclopoids constituted the most important group of Copepoids, followed by calanoids and by harpacticoids.

Concerning the density and the biomass, *Oithona brevicornis* was dominant among the copepodids and adults and respectively represent 36-92% (4-99 ind./L) and 12-90% (1-18 µgC./L). It was followed by *Paracalanus*

spp. [12-24% (≈ 3 ind./L) and 25-36% (≈ 3 µgC./L) and by *Acartia clausi* [1-10% (1-5 ind./L) and 5-54% (1-8 µgC./L)]. *Brachionus plicatilis* constitute the bulk of the Rotifera (0-6 ind./L and < 1 µgC./L). Tintinnids, Cirripedia nauplii (*Balanus* spp.), polychaetes and gastropod larvae, are the most abundant among other zooplankton taxa.

Table I: Mean abundances of the different taxa collected in the Grand-Lahou Lagoon during the diel variation study.

		Station 1		Station 2		Station 3	
		Day	Night	Day	Night	Day	Night
		Abundance (ind./L)					
Rotifera	<i>Brachionus plicatilis</i> (O.F. Müller, 1786)	5.94	1.20	0.11	0.57	0	0.05
Cladocerans	<i>Penilia avirostris</i> (Dana, 1849)	0.01	0.01	0	0	0	0
Copepoda	Nauplii	2.98	8.59	12.03	6.77	18.77	19.70
	<i>Acartia clausi</i> (Giesbrecht, 1849)	0.01	0.05	0.50	0.76	0.72	5.45
	<i>Centropages furcatus</i> (Dana, 1849)	0.07	0.15	0	0	0	0
	<i>Centropages chierchia</i>	0	0.01	0	0	0	0
	<i>Eucalanus</i> spp.	0.05	0.04	0	0	0	0
	<i>Calocalanus pavo</i> (Dana, 1852)	0.01	0	0	0	0	0
	<i>Paracalanus</i> spp.	2.56	3.33	0.22	0.15	0.23	0.22
	<i>Pseudodiaptomus hessei</i> (Mrázek, 1894)	0	0	0.01	0.22	0	0.08
	<i>P. serricaudatus</i> (Scott, 1894)	0.09	0.61	0	0	0	0
	<i>Temora stylifera</i> (Dana, 1849)	0	0.03	0	0	0	0
	<i>Temora turbinata</i> (Dana, 1849)	0	0.01	0	0	0	0
	<i>Temora</i> sp.	0.01	0	0	0	0	0
	Other calanids	0.00	0.01	0	0	0	0
	<i>Corycaeus</i> spp.	0.17	0.25	0	0	0	0
	<i>Oncaea</i> spp.	0.19	0.04	0	0.05	0.01	0
	<i>Oithona brevicornis</i> (Giesbrecht, 1891)	3.86	13.32	42.81	98.70	14.15	26.14
	<i>Euterpina acutifrons</i> (Dana, 1848)	0.29	0.39	0	0	0	0.00
	<i>Microsetella norvegica</i> (Boeck, 1864)	0.05	0.02	0	0	0	0
	<i>Macrosetella rosea</i> (Dana, 1848)	0	0.01	0	0	0	0
	Other harpacticoid	0.25	0.38	0.03	0.46	0.29	2.40
Others	Amphipods	0	0.04	0	0	0.00	0.03
zooplankton	Chaetognatha	0.04	0.44	0	0	0	0.01
	Euphausiacea	0.01	0.21	0	0	0.01	0.01
	Lamellibranche	0.04	0	0	0	0.01	0
	Gastropod larvea	0.22	0.25	0	0	0.20	0.15
	Cirripedia nauplii	0	0	0.02	0	0.01	0
	Polychaete larvae	0	0	0.02	0	0.16	0.76
	Fish larvae	0.11	0.11	0.01	0	0	0.06
	Chironomid larvae	0.07	0.60	0	0	0	0
	Fish eggs	0.04	0.17	0	0	0	0
	Medusea	0	0.14	0	0	0	0
	Decapod Megalopa	0	0.06	0	0	0	0
	Mysidacea	0	0	0	0	0	0.05
	Ostracoda	0	0	0	0	0.00	0.04
	Thaliacea (doliolles)	0	0.01	0	0	0	0
	Decapoda Zoea	0.02	0.06	0	0.05	0.05	0.49
	Lucifer faxoni	0.05	0.10	0	0	0	0
	Tintinnids	5.75	16.79	0	0	0	0
	Insect larvae	0	0	0.00	0.01	0.01	0
	Rotifera	5.94	1.20	0.11	0.57	0	0.05
	Cladocera	0.01	0.01	0	0	0	0
	Copepoda	10.58	27.26	55.60	107.11	34.17	54.01

Other zooplankton	6.35	18.97	0.05	0.06	0.45	1.61
Ecological diversity						
<i>Taxonomic Richness</i>	27	32	11	10	15	18
<i>Shanonn index</i> (bits./ind.)	1.66	1.56	0.57	0.50	0.77	0.83
<i>Pielou evenness</i>	0.56	0.46	0.32	0.18	0.40	0.44

Table II: Mean biomass of the different taxa collected in the Grand-Lahou Lagoon during the diel cycles study.

		Station 1		Station 2		Station 3	
		Day	Night	Day	Night	Day	Night
		Biomass ($\mu\text{gC./L}$)					
Rotifera	<i>Brachionus plicatilis</i> (O.F. Müller, 1786)	0.64	0.13	0	0.00	0.01	0.06
Cladoceran	<i>Penilia avirostris</i> (Dana, 1849)	0.01	0.01	0	0	0	0
Copepoda	Nauplii	0.13	0.39	0.84	0.89	0.54	0.30
	<i>Acartia clausi</i> (Giesbrecht, 1849)	0.02	0.06	0.76	7.61	0.46	0.95
	<i>Centropages furcatus</i> (Dana, 1849)	0.88	1.88	0	0	0	0
	<i>Centropages chierchia</i>	0	0.18	0	0	0	0
	<i>Eucalanus</i> spp.	0.98	0.83	0	0	0	0
	<i>Calocalanus pavo</i> (Dana, 1852)	0.07	0	0	0	0	0
	<i>Paracalanus</i> spp.	2.67	3.47	0.24	0.23	0.23	0.16
	<i>Pseudodiaptomus hessei</i> (Mrázek, 1894)	0	0	0	0.36	0.03	0.59
	<i>P. serricaudatus</i> (Scott, 1894)	0.49	3.35	0	0	0	0
	<i>Temora stylifera</i> (Dana, 1849)	0	0.11	0	0	0	0
	<i>Temora turbinata</i> (Dana, 1849)	0	0.06	0	0	0	0
	<i>Temora</i> sp.	0.03	0	0	0	0	0
	Other calanids	0.02	0.08	0	0	0	0
	<i>Corycaeus</i> spp.	0.13	0.19	0	0	0	0
Copepoda	<i>Oncaea</i> spp.	0.15	0.03	0.01	0	0	0.04
	<i>Oithona brevicornis</i> (Giesbrecht, 1891)	0.87	2.41	1.91	4.87	4.34	18.44
	<i>Euterpina acutifrons</i> (Dana, 1848)	0.57	0.79	0	0.01	0	0
	<i>Microsetella norvegica</i> (Boeck, 1864)	0.04	0.02	0	0	0	0
	<i>Macrosetella rosea</i> (Dana, 1848)	0	0.01	0	0	0	0
	Other harpacticoid	0.02	0.03	0.02	0.21	0.00	0.04
Others zooplankton	Amphipods	0	1.82	0.16	1.51	0	0
	Chaetognatha	0.04	0.48	0	0.01	0	0
	Euphausiacea	1.52	45.04	1.52	2.10	0	0
	Lamellibranche	0.00	0	0.00	0	0	0
	Gastropod larvea	0.09	0.11	0.08	0.06	0	0
	Cirripeda nauplii	0.06	0.06	0.00	0	0.01	0
	Polychaete larvae	0.04	0.33	0.09	0.42	0.01	0
	Fish larvae	0.69	3.03	0	1.04	0.13	0
	Fish eggs	0	0.15	0	0	0	0
	Medusea	0.04	0	0	0	0	0
	Mysidacea	0	0	0	10.22	0	0
	Ostracoda	0	0.01	0.01	0.08	0	0
	Larva	0.01	0.03	0	0.00	0	0
	Decapoda Zoea	0.04	0.08	0.04	0.40	0	0.04
	Tintinnids	0.23	0.68	0	0	0	0
	Rotifera	0.64	0.13	0	0.00	0.01	0.06
	Cladocera	0.01	0.01	0	0	0	0
	Copepoda	7.08	13.92	3.78	13.81	5.58	19.93
	Others zooplankton	2.74	51.86	1.90	15.83	0.15	0.04
	Total zooplankton	10.46	65.92	5.68	29.65	5.74	20.03

C. Zooplankton diversity and composition diel variation

No diel variation pattern was obtained for the three diversity index studied. No important night-day variation was either observed. However, the number of zooplankton taxa recorded during the night (9 to 27, mean: 15.11 taxa) was greater than that observed during the day (6 to 20, mean: 12.50 taxa). Taxonomic richness diel variation is significant at station 1 (15 to 20 taxa in the day vs. 18 to 27 at night). Station 1 presented the most important

taxonomic richness values (15 to 27 taxa) vs. 6 to 13 taxa at stations 2 and 3.

Total zooplankton abundance and biomass sampled during the diel study were highly variable, ranging from 26 to 93 ind./L and from 4 to 57 $\mu\text{gC/L}$, respectively. Generally, total zooplankton abundance and biomass diel variations were characterized by the night values (respectively 31 to 175 ind./L and 11 to 135 $\mu\text{gC/L}$) higher than the day ones (respectively 10 to 94 ind./L and 2 to 12 $\mu\text{gC/L}$) (Figure 4).

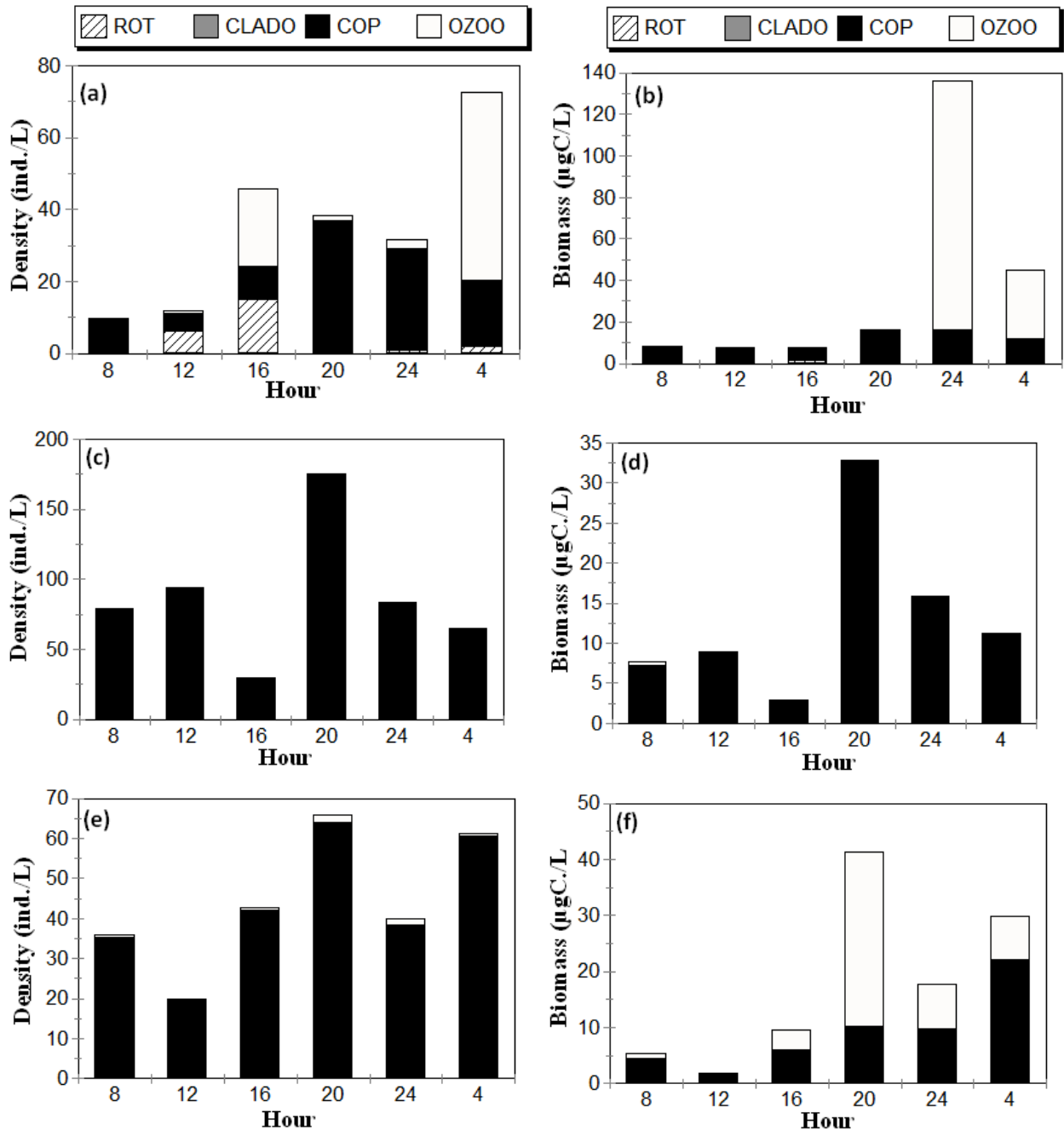


Fig.4. Diel variations of density (on the left) and of biomass (on the right) of the main zooplankton groups sampled in Grand-Lahou lagoon during the dry season (March-April): (a and b) - Station 1; (c and d) - Station 2 and (e and f) - station 3. (ROT : Rotifers, CLADO : Cladocerans, COP : Copepods, OZOO : Other zooplankton).

During the day time, copepod group dominated the zooplankton population, in terms of abundance, excepted at 16:00 and at 4:00 at station 1, where others zooplankton constitute the most dominant group [(48%, 22 ind./L) and (72%, 52 ind./L) respectively] (Figure 4a).

In terms of biomass, the population is dominated by the copepod during the day at all stations. At night, zooplankton population was dominated by others zooplankton group at station 1 (70 to 90% at 24-04:00) (Figure 4b) and by copepod at station 2 ($\approx 100\%$) (Figure 4d).

At station 3, others zooplankton group was dominant at 20:00 (76 %) whereas copepod was dominant at 24:00 (53%) and at 4:00 (73%) (Figure 4f). Rotifer was observed with significant relative abundance in station 1, at 12:00 (53%) and at 16:00 (33 %) (Figure 4f).

Total copepod abundance and biomass diel variations were similar to those of the total zooplankton, with highest values observed at night (18 to 174 ind./L and 10 to 33 $\mu\text{gC/L}$) versus (5 to 94 ind./L and 3 to 10 $\mu\text{gC/L}$ during the daytime) (Figure 5).

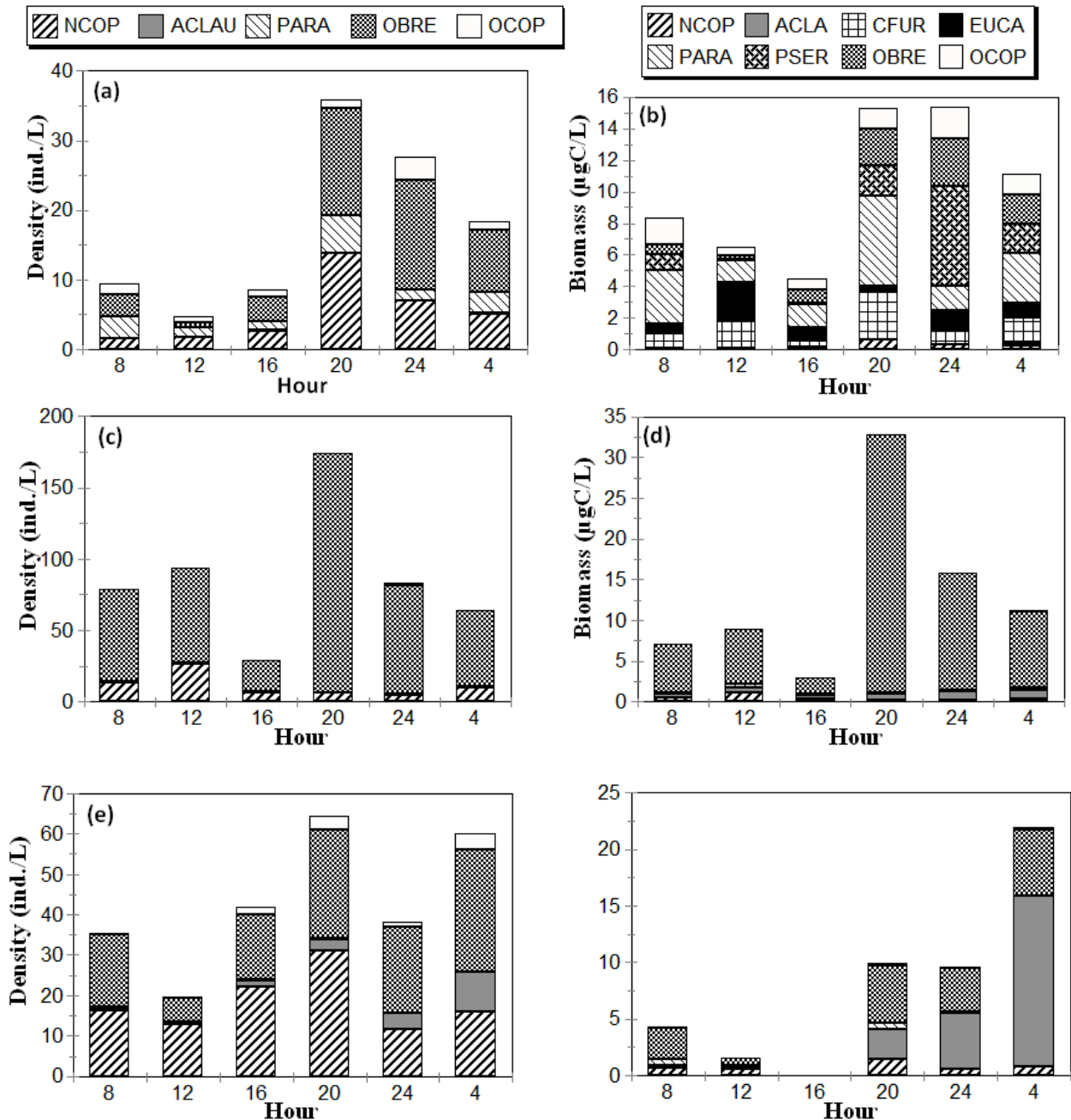


Fig.5. Diel variations of density (on the left) and of biomass (on the right) of the main copepods sampled in Grand-Lahou lagoon during the dry season (March-April): (a and b) - Station 1; (c and d) - Station 2 and (e and f) - station 3. (NCOP : Copepods nauplii, OBER : *Oithona brevicornis*, OCOP : Other copepods, ACLA : *Acartia clausi*, PARA : *Paracalanus* spp., CFUR : *Centropages furcatus*, EUCA : *Eucalanus* spp., PSER : *Pseudodiaptomus sericaudatus*).

During the diel variation, the dominant copepod taxon in abundance terms, was *Oithona brevicornis*. It constituted, on the average, between 45 to 85% of total copepod abundance and showed its highest abundance at night (8 to 167 ind./L versus 1 to 66 ind./L during the day time) (Figure 5a, c and e). Others taxa presented greatest biomass at night. These are *Pseudodiaptomus serricaudatus* (2 to 8 $\mu\text{gC/L}$ versus $< 1 \mu\text{gC/L}$ during the day) and *Paracalanus* spp. (2 to 6 $\mu\text{gC/L}$ versus 1 to 3 $\mu\text{gC/L}$ during the day) at station 1 (Figure 5b); and *Acartia clausi* (3 to 15 $\mu\text{gC/L}$ versus $< 2 \mu\text{gC/L}$ during the day) at station 3 (Figure 5f).

During the 24-h cycle, the other zooplankton group abundance and biomass varied according to the stations (Figure 6). At station 1, two abundances peaks were displayed at 16:00 (22 ind./L) and at 4:00 (52 ind./L) (Figure 6a) whereas the most elevated biomass have been obtained at night (121 $\mu\text{gC/L}$ at 24:00 and 34 $\mu\text{gC/L}$ at 4:00) (Figure 6b). The highest peak obtained was due to tintinnid abundant while the biomass peak was due to euphausiacea. At station 2, two abundances peaks were also observed, at 12:00 (0.11 ind./L) and at 4:00 (0.8 ind./L) (Figure 6c) whereas the most elevated biomass have been observed at 8:00 (0.53 $\mu\text{gC/L}$) (Figure 6d).

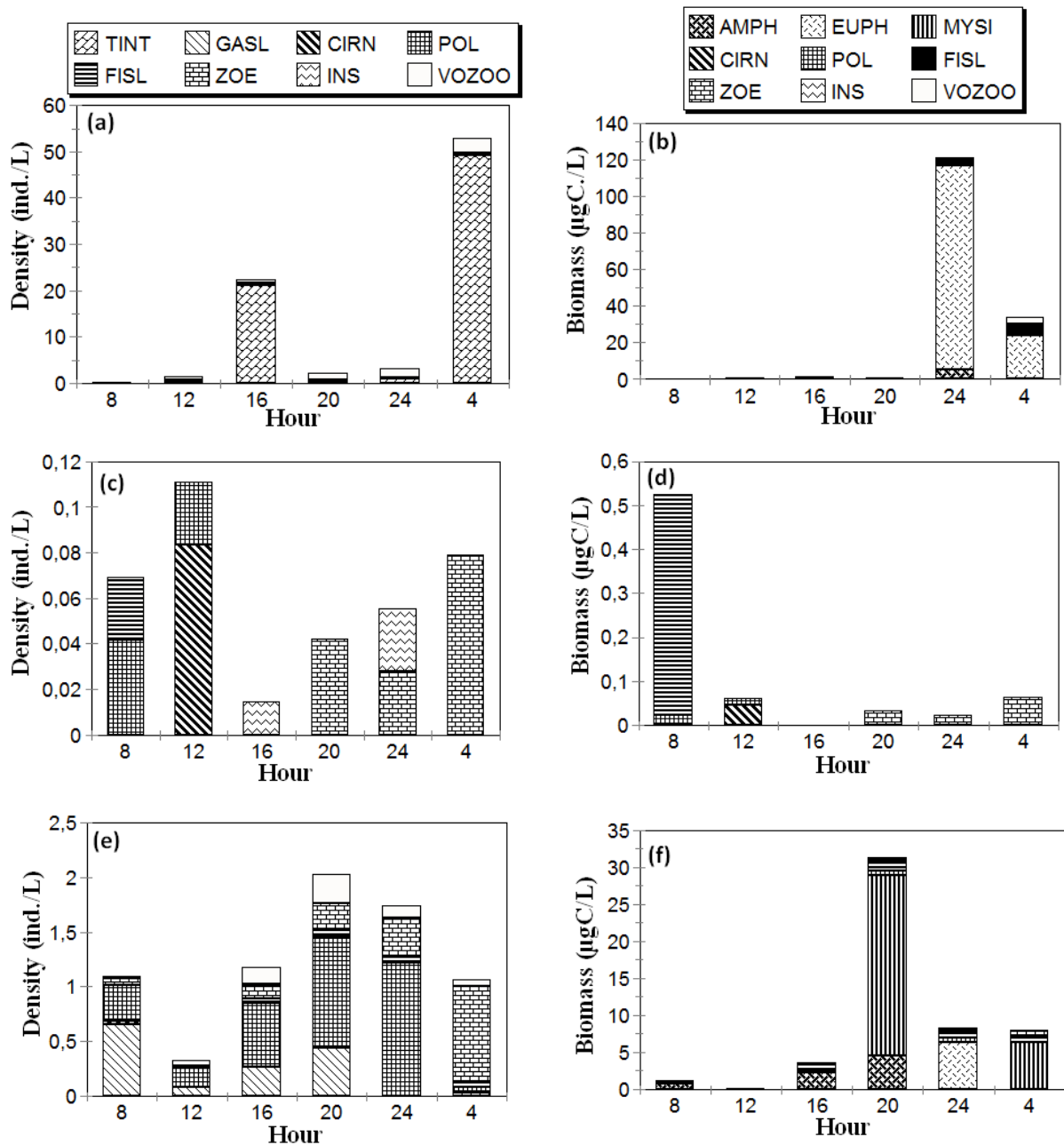


Fig.6. Diel variations of density (on the left) and of biomass (on the right) of the main taxa of other zooplankton sampled in Grand-Lahou lagoon during the dry season (March-April): (a and b) - Station 1; (c and d) - Station 2 and (e and f) - station 3. (CIRN : Cirripedia Nauplii, POL : Polychaetes larvae, FISL : Fish larvae, ZOE : Decapoda zoea, GASL : Gastropod larvae, AMPH : Amphipods, EUPH : Euphausiacea, MYSI : Mysidacea, TINT : Tintinnides, INS: Insect, VOZOO : Various other zooplankton).

At 12:00, the abundance peak was due to cirripedia nauplii and to polychaetes larvae whereas at 4:00, abundance peak was due to decapoda zoea. During the 24-h cycle at station 2, decapoda zoea was obtained at nighttime while cirripedia nauplii, polychaetes larvae were observed at daytime. Biomass peak recorded at 8:00 was due to mainly to fish larvae. In station 3, zooplankton diel variation was marked by the most elevated abundance and biomass values obtained at nighttime (1 to 2 ind./L and 8 to 31 $\mu\text{gC./L}$) versus $\leq 1 \text{ ind.l}^{-1}$ and 0 to 16 $\mu\text{gC./L}$ in the daytime (Figure 6e and f).

Abundance peaks observed at night were mainly due polychaetes larvae and decapoda zoea (Figure 6E) while

biomass peaks were mainly due to mysidacea and Euphausiacea (Figure 6f).

Rotifera represented by *Brachionus plicatilis* was shown diel variation marked by highest abundance and biomass at daytime, in station 1 (6 to 15 ind./L and 0.7 to 1.6 $\mu\text{gC./L}$ versus $< 2 \text{ ind./L}$ and $< 0.5 \mu\text{gC./L}$ at night) (Figure 7a and b).

To the stations 2, on the other hand, the most abundance and biomass values were obtained at nighttime (0.5-0.6 ind./L and 0.05-0.07 $\mu\text{gC./L}$) versus $< 0.1 \text{ ind./L}$ and $< 0.01 \mu\text{gC./L}$ at daytime (Figure 7c and d). During the 24-h sampling, Rotifera was not obtained in station 3.

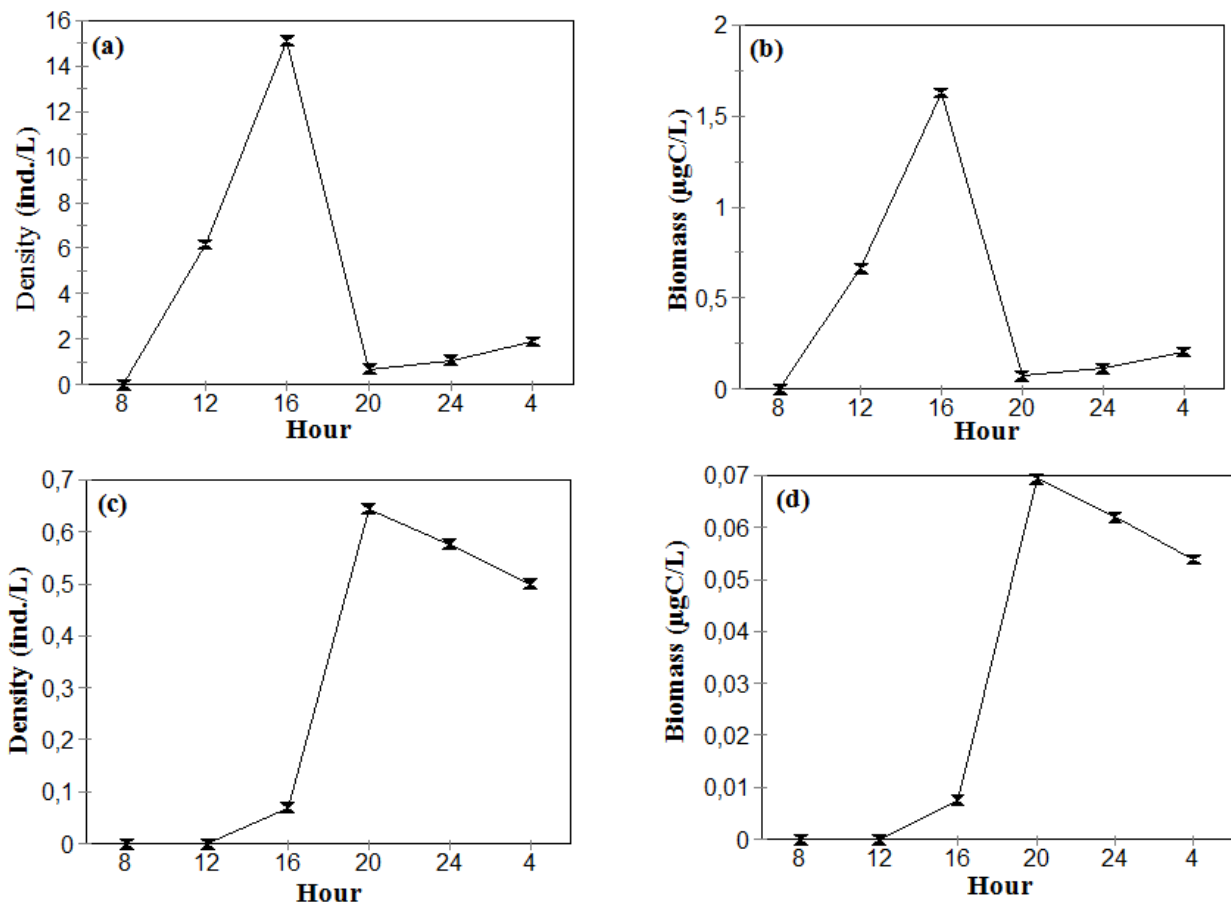


Fig.7. Diel variations of density (on the left) and of biomass (on the right) of *Brachionus plicatilis* sampled in Grand-Lahou lagoon during the dry season (March-April): (a and b) - Station 1 and (c and d) - Station 2.

D. Relations between zooplankton taxa and environmental variables

The relationship between zooplankton density and environmental variables is shown in the RDA ordination diagram (Figure 8). The cumulative percentage variance expressed by the first two axes was 83%, with 66% for the first axis.

Analysis showed a clear discrimination of sampling sites. The first station, near the Grand-Lahou channel, was positively correlated with the 1st axis and was characterized by high values of dissolved oxygen, conductivity and pH. At the biologic level, this station was

characterized mainly by *Paracalanus* spp., *Euterpina acutifrons*, *Pseudodiaptomus sericaudatus*, Tintinnids and *Brachionus plicatilis*.

The two other stations, more distant of the channel, were negatively correlated with the 1st axis. Station 2 was marked by high values of ammonium and phosphates, and was characterized by taxa composing *Oithona brevicornis*, Euphausiacea, Cirripedia Nauplii, Mysidacea, *Acartia clausi*, and Decapoda zoea. Station 3 was characterized by high values of temperature and by Copepods nauplii and Polychaetes larvae.

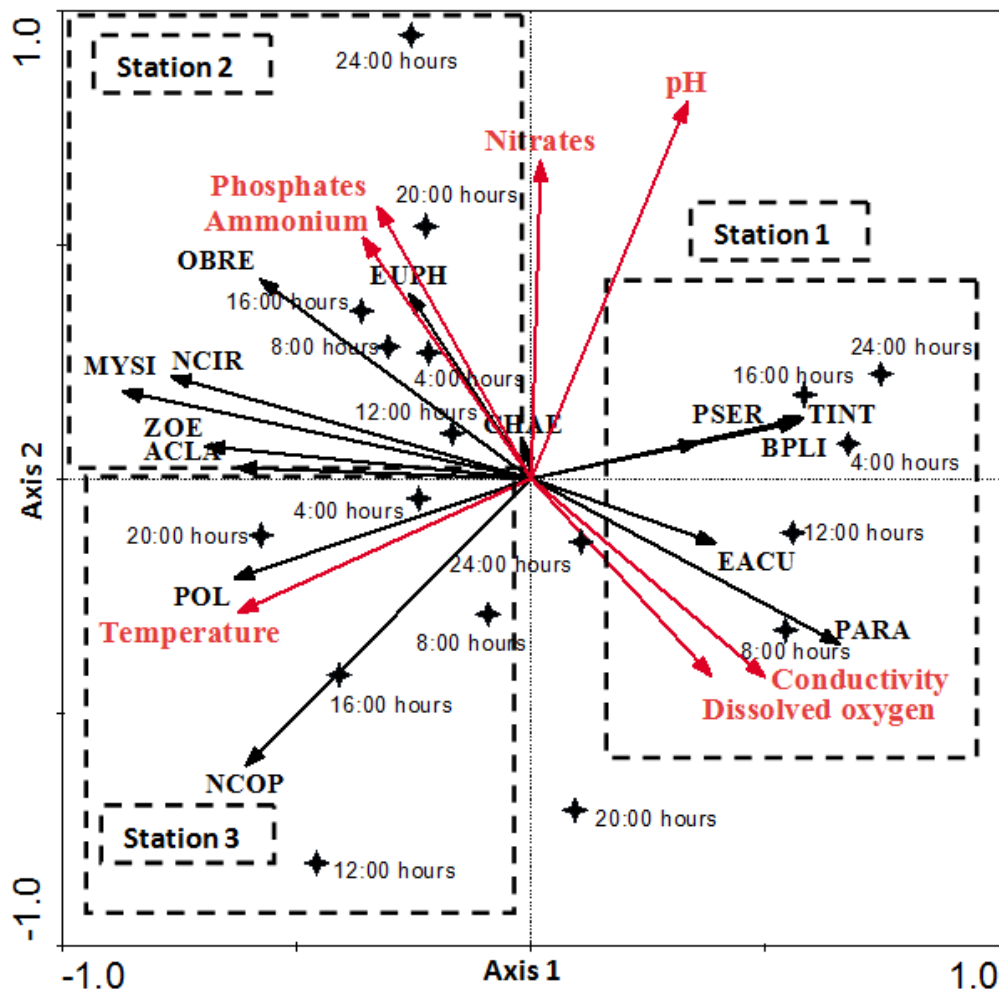


Fig.8. RDA analysis showing biplot of zooplankton taxa and environmental variables in Grand-Lahou lagoon. (PARA : *Paracalanus* spp., EACU: *Euterpina acutifrons*, BPLI: *Brachionus plicatilis*, CHAE: Chaetognath, PSER : *Pseudodiaptomus sericaudatus*, TINT: Tintinnids, OBER : *Oithona brevicornis*, EUPH : Euphausiacea, CIRN : Cirripedia Nauplii, MYSI : Mysidacea, ZOE : Decapoda zoea, ACLA : *Acartia clausi*, NCOP : Copepods nauplii, POL : Polychaetes larvae).

IV. DISCUSSION

A total of Forty-one zooplanktonic taxa were identified in all the sampling stations during our circadian cycle study during the dry season. These taxa are divided into four groups Copepoda, Rotifera, Cladocera, and other zooplankton mainly of marine and brackish origin. Copepods and other zooplankton were the most important group in terms of diversity; they were respectively represented by twenty (49 % of total taxa) and nineteen taxa (46 %). During the rainy and flood season, [16] found that the zooplanktonic community is composed of brackish and freshwater zooplankton such as *Brachionus falcatus*, *B. caudatus*, *Filinia opoliensis*, *F. longiseta*, *F. terminalis*, *Diaphanosoma excisum*, *Moina micura*, *Mesocyclops* sp., etc.

The difference between the communities observed during the dry season and the wet and flood seasons confirms the dependency of the structure of zooplanktonic community on the hydroclimatic factors. It is the major reason zooplankton has been used as a sensitive tool for

monitoring environmental changes in coastal lagoons; hence, zooplankton can provide useful information for a sustainable management of these sensitive ecosystems.

Copepods constituted the most dominant group among the zooplanktonic community observed in the Grand-Lahou lagoon, with 46 % to $\approx 100\%$ and 53-97% respectively of the total zooplankton density and biomass ([16], [33]). Among these Copepod species, one can observe the predominance of *Oithona brevicornis* in the Grand-Lahou lagoon. The numerical predominance of *Oithona* species is also reported in the Cananéia lagoon (Brazil) [34], in the North Queensland (Australia) [35] and in the Ebrié lagoon [36].

Oithona brevicornis's predominance in Grand-Lahou lagoon could be explained by the stronger marine influence on this ecosystem on the one hand, and by the relative tolerance of *Oithona brevicornis* to the high salinity levels (5-30) on the other hand [37]. According to [38], the numerical predominance of *Oithona* species seems to be a general characteristic of mangrove copepod community.

Indeed, *Oithona* species are more capable to eat particulate organic matter of variable diameter between 2.5 and 5 μm s and coming from the mangrove [39].

A positive relationship between *Oithona brevicornis* reproduction parameters and salinity was observed by [40].

The zooplankton abundance and biomass showed a substantial increase during the night in all stations. Besides, some zooplankton organisms presented biomass diel variations in relation to tide. Nocturnal increase of zooplankton abundance and biomass has been reported by several studies ([41], [42], [13], [43], [44]-[45]). Zooplankton density and biomass nocturnal augmentation may be due to diel vertical migration of some organisms ([45], [46]-[47]). The 'normal' pattern of zooplankton migration is a morning descent and an evening ascent. In the other words, migrating animals spend the day in deep waters and the night near the surface waters ([48]. The amplitude of the vertical movements may be very different between species and between ontogenetic stages of the same species. Several factors were used to explain zooplankton vertical migration, among which predator avoiding, food research, light intensity variation ([22], [49] in [50]).

Evidence has accumulated for an important role of predation in driving diel vertical migration. The first experimental evidence for the importance of predators come from studies of Gatun lake in Panama and Fuller Pond in Connecticut [51]. Other studies also show that daytime zooplankton descent is a strategy to avoid predation by abundant visual predators such as fish and invertebrate ([7], [52]). Some larger individuals experience a greater susceptibility to visual predators; they descend and spend the day time near the bottom and ascent in water column during the night [53]. The nocturnal increase in *Pseudodiaptomus serricaudatus* (station 1), *Acartia clausi* (station 2), Amphipods (station 1 & 2), Euphausiacea (station 1 & 2) and Mysidacea (station 2) biomass (Table II and Figure 3 and 4) could be explained by the susceptibility of these organisms to visual predation. Although, this study was not devoted to vertical migration study of zooplankton, it is noteworthy that some previous study reported that these organisms make daily vertical migrations or that some of their congeneric species make it ([13], [46], [50]).

In several studies, zooplankton migration toward the superficial layers during the night coincides with the increase of nocturnal food activity of some taxa. This was observed for *Acartia tonsa* in Berre pond (France) [54], for *Acartia clausi* in the Ebrié lagoon (Côte d'Ivoire) [13], for *Pseudodiaptomus hessei* and *Acartia longipatella* in the Cap estuary (South Africa) [50] and for *Rhopalophthalmus africana* in the Ebrié lagoon (Côte d'Ivoire) [46]. These studies have concluded that the migration of the zooplanktonic communities from the bottom toward the water column during the night was in relation with food research or availability. However, it also arrived that the period of maximum food doesn't coincide with the zooplankton nocturnal vertical ascent,

e.g., *Pseudodiaptomus hessei* [46] and *Acartia clausi* [55] in Ebrié lagoon.

In addition, light intensity variations are also used to explain diel vertical migration observed at some zooplanktonic organisms ([46], [56]-[57]). The diel vertical migration of *Daphnia* was reduced meaningfully in amplitude (less than 2 m) and in magnitude (10-20% less individuals) in the lakes exposed to the urban lights [58]. Furthermore, females and the nauplii stages of *Calanus finmarchicus* migrated when they were exposed to ultraviolet (UV) radiations. Nauplii stages reacted mainly in the UV-B radiation, whereas the females reacted in the UV-A radiation [59]. On the contrary, [60] didn't shown statistically significant difference in the daytime depth distributions of *Acartia hudsonica* adult stage when they are exposed to ultraviolet B (UV-B) radiations and concluded that some other factor(s) must determine the daytime vertical distribution of this copepod.

Our survey permitted to observe zooplankton composition, density and biomass short-term dynamic was related to tide cycle, mainly to the station 1. In this station, total zooplankton and tintinnids higher density have been observed to the low tide (16:00 and 4:00). On the other hand, higher density and biomass of *Paracalanus* spp. have been observed to the high tide (8:00 and 20:00). Previous studies reported zooplankton composition and abundance variation in relation to tide. In a macrotidal mangrove channel (Northern Brazil), [61]Krumme and Liang (2004) reported that the abundance and biomass of both total zooplankton and copepods were high at low water. They also observed that the density and the biomass of *Pseudodiaptomus marshi* (dominant copepod of this ecosystem) presented similar variation.

In contrast, [62] recorded that there was no evidence of any significant variation in zooplankton or copepods in relation to either tidal level, in the Taperaçu estuary (northern Brazil). According to [63], the tide cycle induced fluctuations of environmental variables as hydrostatic pressure, turbulence and stirring of water, temperature, salinity, current speed. The variation of these parameters encourages some changes in zooplankton composition and the density. For [64], the advection by the current constitutes a source of meaningful variability of the zooplankton density in estuary and lagoons, which affects all stages of zooplankton development including eggs production, young and adult phases. The tidal effect is felt more at station 1 (located near the Channel) than at stations 2 and 3. Zooplankton composition and density changes under tidal effect is in direct relation with tide phase (ebb and flood tide). During the flood tide, station 1 located near the channel is invaded by marine zooplankton taxa; while, brackish community taxa is predominant during the ebb tide. One can also observe some few marine taxa organisms the ebb period. On the contrary, the tide doesn't affect the zooplankton structure at stations 2 and 3 situated far from the channel. Zooplankton community change in these stations is a lot more in relation with the phase of day resulting in a nocturne increase of the zooplankton density.

V. CONCLUSION

This was the first study to examine zooplankton composition, abundance and biomass variation during 24-h sampling cycles in Grand-Lahou Lagoon. Our study also proposes a pattern of short-term temporal variations of the zooplankton community and abundance in relation with environmental variables. Observation of diel variation in zooplankton at four-hour intervals revealed that zooplankton constitutes a sensitive tool for monitoring environmental changes in coastal lagoons because of its reaction to waters masses change. This study revealed that, in Grand-Lahou lagoon, diel variation in zooplankton composition, abundance and biomass is due to phases of day and tidal cycle in zones near of the channel and mainly due to day cycle in the over sites.

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