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An Unusual Distribution of *Oithona nana* GIESBRECHT (1892) (Crustacea:Cyclopoida) in a Bay: The Case of Toulon Bay (France, Mediterranean Sea)

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ABSTRACT

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The distribution of the Cyclopod *Oithona nana* in Toulon Bay (France, Mediterranean Sea) was studied. This bay has an artificial breakwater which creates two sub-ecosystems, an inner little bay (heavily polluted) and an outer large bay (less polluted). We set up six sampling stations in the inner bay and nine outside, along a littoral/pelagial gradient. Zooplankton hauls were taken with a 90 μm mesh plankton net (with flowmeter). The sea surface temperature, conductivity and salinity were also measured. The abundance of *O. nana* was much higher in the little bay than outside. There were also very few males in the little bay, and almost none in the large bay, in contrast to the abundant females in the sampling stations adjacent to the little bay. The sex-ratio was always in favour of females and there were more adults than copepodites. These results indicate that the ecological status of the little bay favours the development of *O. nana,* and we suggest that this species may be used as a biological indicator of such perturbed systems.

ADDITIONAL INDEX WORDS: *Oithona nana, distribution, coastal ecosystem, anthropogenic inputs.*

INTRODUCTION

There has been considerable ecological and economic in ecotones like coastal marine ecosystems over the past few years. These ecotones, situated between terrestrial and marine ecosystems, have long received the bulk of the human-generated municipal and industrial waste that enters the oceans from the land, making many of them heavy polluted (KENNISH, 1992; SCHUBEL, 1994).

Toulon Bay (France) is on the north coast of the Mediterranean Sea and is greatly influenced by such anthropogenic inputs as organic, chemical (anti-fouling paints) and biological (toxic phytoplanktonic species) pollutions (GUILLAUD and ROMANA', 1991; BELIN *et al.,* 1995). It also has a large amount of maritime traffic due to military and commercial activities. This bay is divided by an artificial breakwater which creates two sub-ecosystems: inside is the heavely polluted little bay and the large outer bay is less polluted.

Previous works on this bay (JAMET and FEREC-CORBEL, 1996; JAMET *et al.,* 1998; JAMET *et al.,* in press) showed that the structure of the zooplankton community in the little bay is very different from that of the large bay. These studies also indicated that the small Cyclopoid *Oithona nana* GIESBRECHT (1892), an euryhaline species wide ecological tolerance that is distributed throughout Mediterranean Sea (KRSINIC, 1995; RAZOULS, 1996), is by far the dominant species in the little bay, and its abundance may be 10–50 times more than outside.

We have attempted to better understand this sudden difference in the distribution of *O. nana* in the two sub-ecosystems of the Bay of Toulon. We took several samples of zooplankton using a 90 μm mesh (rather than the standard 200 μm mesh Mediterranean plankton net) along a transect from the littoral zone of the little bay to the other littoral zone of the large bay, crossing the pelagial areas of the two zones. This study will provide on the distribution of zooplankton for a single species. Our findings suggest that *O. nana* could be used as a biological indicator of polluted systems and furthermore, according to ARCHAMBAULT *et al.* (1998), no one appears to have compared the zooplankton groups within and outside embayments.

MATERIAL AND METHODS

Sampling and Analysis

The zooplankton samples were taken at 15 stations along a transect (Figure 1). The depth of the water column varied from 7 to 35 m. The water temperature (± 0.1 °C), conductivity (±0.1 mS · cm^{-1}) and salinity (± 0.1 psu) were measured at the sea surface at each sampling station with a ProfiLine Conductivity Meter type WTW LF 197. Samples

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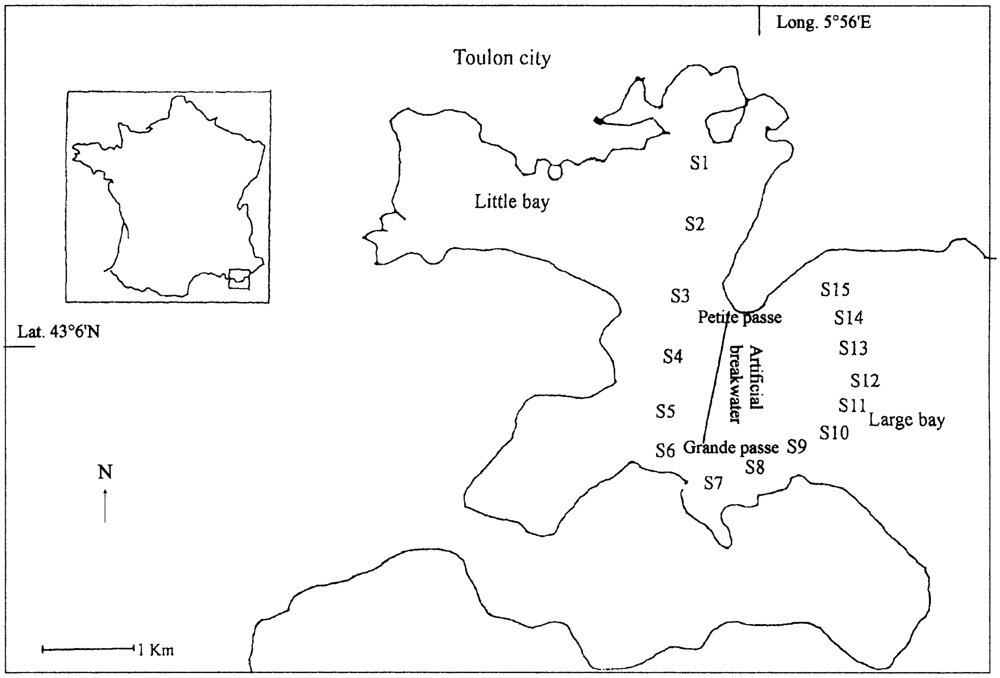

Figure 1. Localisation of the 15 sampling stations (1 to 6: little bay; 7 to 15: large bay) in Toulon Bay.

were taken with a plankton net type General Oceanic 5125 (diameter 0.5 m, length 2.5 m, 90 μm mesh size) by vertical hauls. The volume of water filtered was measured by a flowmeter. Samples were immediattely stored in buffered ($CaCO_3$) 5% formalin seawater. Random subsamples were drawn using a Hensen pipette from the sample adjusted to 250 ml. All the zooplankton were indentified to the nearest taxonomic group (species and development stages if possible) and counted. This study focused on *O. nana*. The sex-ratio of *O. nana* was calculated as the number of males against the number of females. Significant differences between the little and large bays were tested by Student's t-test for the physical and chemical parameters, and by the Mann-Whitney U-test for samples (abundance) from the different sampling stations for the zooplankton community.

Study Area

Toulon Bay (central point for this study: Lat. 43° 6′ N and Long. 5° 56′ E) is on the French mediterranean coast. Surface currents (from West to East and from East to West) are generated in the bay by the dominant winds (N.-W. and S.-E.). The main under current in the bay is from N.-W. to S.-E. (PAILLARD *et. al.*, 1993). There is a great deal of shipping due to military and commercial activities. The REPHY data (French Phytoplankton Monitoring Network) indicate high levels of PAH, PCB and heavy metals (mercury, lead) (IFREMER, 1993). The bay is divided by an artificial breakwater into two sub-ecosystems, the little bay (inside) and the large bay (outside). The two bays communicate by the "Petite Passe" (to the north) and the "Grande Passe" (to the south). The hydrodynamic characteristics of the little bay are summarized in Table 1 (TINE *et al.*, 1981).

This study covered station 1 to station 6 in the little bay and station 7 to station 15 in the large bay. A previous study (JAMET and BOGE, 1998) showed that chlorophyll *a* and phosphatasic activities of organisms were much higher in the inside bay than in the outside, one suggesting a higher trophic degree and a different structures and functions in the two sub-ecosystems. *Posidonia oceanica* is also absent from the little bay, but abundant in the outside bay, indicating a better ecological water quality in the large bay.

Table 1. *Hydrodynamic characteristics of the little bay of Toulon Bay.*

Surface	11 km^2
Volume	$1 \cdot 10^8$ m^3
Tide level	15 cm
Input and output of water in 24 h	$3.3 \cdot 10^6$ m^3
Residence time of sea water	*ca.* 3–6 days
Mean flow at the "Grande Passe"	76 $m^3 \cdot s^{-1}$
Maximum speed of the current at the "Grande Passe"	0.66 $cm \cdot s^{-1}$

RESULTS

Water Quality

The water temperature in the little bay ranged from 12.9 to 13.4 °C with a mean value of 13.2 °C (± 0.08) and was significantly lower ($p < 0.05$) than in the stations of the large bay (13.5 < T °C < 13.7; mean value = 13.6 °C ± 0.02). At contrary, there was no significant difference between the two sub-ecosystems for conductivity (mean value in little bay =

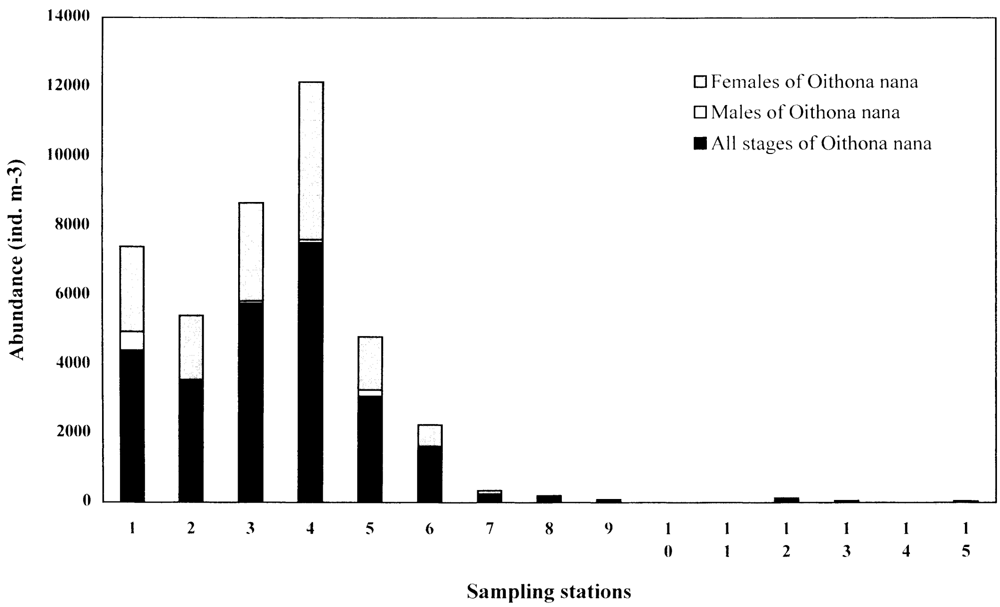

Figure 2. Abundance (ind · m $^{-3}$) of females, males and all stages of development (adults and copepodites) of *Oithona nana* at the 15 sampling stations in Toulon Bay.

51.6 mS · cm $^{-1}$ ± 0.02; large bay = 51.4 mS · cm $^{-1}$ ± 0.17) and salinity (mean value in little bay = 37.6 psu ± 0.02; large bay = 37.4 psu ± 0.1). These water quality parameters produced no gradient along the 15 sampling stations.

Overview of the Zooplankton Community

The principal taxonomic groups were: Cladocera (*Evadne nordmanni* and *E. spinifera; Podon polyphemoides*), Copepoda (*Oithona* spp., *Oncaea* spp., *Corycidae* spp., *Euterpina acutifrons, Microsetella norvegica,* nauplii of Calanoidia and Cyclopoida; copepodites and adult stages of other Calanoida and Cyclopoida) and other invertebrates (medusa larvae, nematods, polychete larvae, gasteropod larvae, bivalve larvae, nauplii of Cyrripeds, echinoderm larvae).

Copepod nauplii were abundant in both sub-ecosystems (3996 ± 1121 and 2497 ± 718 ind · m $^{-3}$, respectively), but with a significantly ($p < 0.05$) higher abundance in the little bay.

There were significantly ($p < 0.05$) more Calanoida (adults and copepodites) in the large bay than in the small one (1880 ± 552 and 2589 ± 924 ind · m $^{-3}$, respectively). They were, with the Copepod nauplii, the main taxonomic group in the zooplankton community in the large bay (> 60%). The distributions of the principal zooplankton groups between the two sub-ecosystems showed that *O. nana* was far more abundant in the little bay than in the large bay. This was the only taxonomic group or species that showed such a great difference.

Oithona nana

O. nana (adults and last stages of copepodites) accounted for up to 46% of the total number of postnaupliar copepods and holoplankton in the perturbed little bay and only 1.03% in the large bay. This difference was highly significant ($p < 0.01$) and corroborated our previous studies which showed that this proportion could reach over 85–90%, depending on the season.

The abundance of *O. nana* (all stages together) in the little bay (mean value = 4317 ind · m $^{-3}$ ± 2095) was significantly higher ($p < 0.01$) than in the large bay (mean value = 79 ind · m $^{-3}$ ± 87) (Figure 2). High densities were noted in the pelagial zone (station 4 with 7519 ind · m $^{-3}$) and *O. nana* numbers decreased going to the large bay *via* the "Grande Passe" (stations 5 and 6: 3078 and 1584 ind · m $^{-3}$, respectively). There was also a gradient of decreasing abundance in the distribution of this copepod across the large bay (stations 7, 8 and 9: 240, 177 and 55 ind · m $^{-3}$).

There were fewer males of *O. nana* and they were found only in the little bay (mean = 152 ind · m $^{-3}$ ± 197) (Figure 2), with a maximum at the more littoral sampling station (534 ind · m $^{-3}$). We found no males of *O. nana* in the large bay (Figure 2). However, females were found only at stations 7 (107 ind · m $^{-3}$), 8 (25 ind · m $^{-3}$) and 9 (37 ind · m $^{-3}$) in the large bay, near the "Grande Passe." The distribution of females seemed to be along a gradient from the littoral area in the little bay that increased in the pelagial zone and decreasing going to the large bay.

This situation created a variation in the sex-ratio variation of *O. nana* in the sampling stations (Figure 3). The ratio was always severely negative (0.02–0.22), indicating that females were much more abundant than males. Most copepodites of *O. nana* were found in the little bay (mean abundance in the little = 1849 ind · m $^{-3}$ ± 826 and 60 ind · m $^{-3}$ ± 64 in the large bay). Here again there was a decreasing gradient of abundance from station 4 (2885 ind · m $^{-3}$) in the little bay to

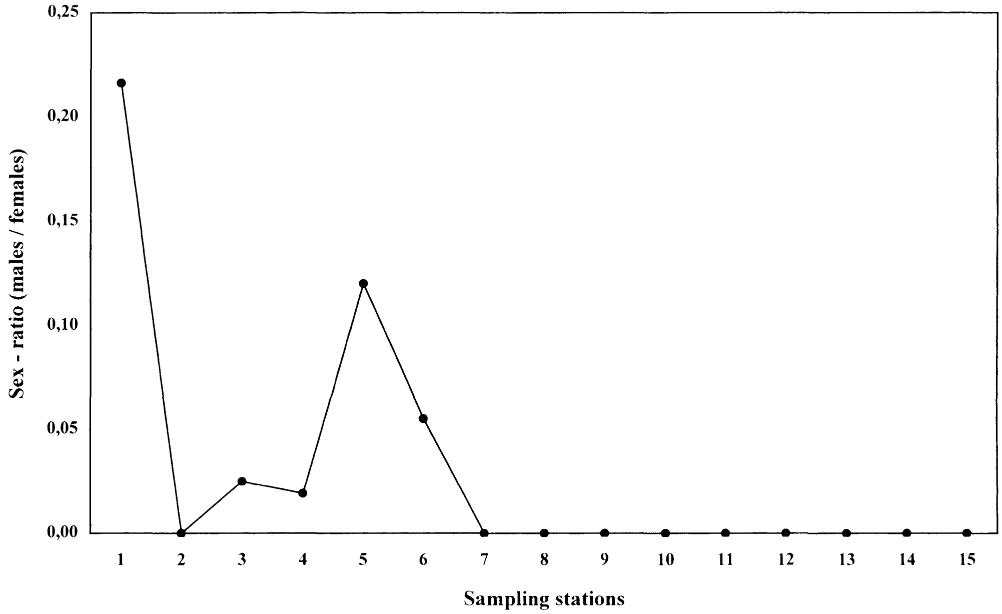

Figure 3. Sex-ratio (males/females) of *Oithona nana* at the 15 sampling stations in Toulon Bay.

the large bay (*i.e.* station 9 : 18 ind · m^{-3}). Except for the stations located near the "Grande Passe" (stations 6, 7 and 8) where the adult-copepodite ratio was less than unity (Figure 4), adults were always more abundant than copepodites (ratio 1.02–2.14).

DISCUSSION

The sampling stations were chosen to reveal a gradient of distribution of *O. nana* from the little bay to the large bay and set along a transect from the littoral area to a more pelagial one. The distribution of this copepod did not seem to be influenced by the a littoral/pelagial conditions but by the ecological status of the two sub-ecosystems. Although there is probably a relative high water exchange between the two bays, this Cyclopoid had a markedly different distribution.

O. nana is a tolerant, opportunistic and widely adapted species and several studies indicate that this Cyclopoid occurs in sea ports and near urban wastes with different degree of pollution and/or in brackish water (see YAMAZI, 1956, 1964; LAKKIS and ABBOUD, 1976; ARFI *et al.*, 1981; LAMPRIT and GAMBLE, 1982; LOKMAN, 1993; KRSINIC, 1995). In Toulon Bay, previous studies (JAMET and FEREC-CORBEL, 1996; JAMET *et al.*, 1998; JAMET *et al.*, in press) indicated clearly that *O. nana* was the dominant species of the holoplankton (at least 70% of the whole zooplankton community) in the severly perturbed little bay during all the periods of the year. These results seemed to indicate that this Oithonidae was a typical and characteristic species of rich, polluted marine water like that of the little bay of Toulon.

In this study, the water temperature in the little bay was slightly lower than outside, as noted in our previous works for winter. This is in agreement with PATRITI (1972) who found that closed or semi-closed systems, like harbours (*i.e.* Marseille) or bays, were more sensitive to the climatic conditions of winter. But, here the variation in water temperature cannot explain the difference in the distribution of the euryece *O. nana*. In addition, there was no significant difference in the other abiotic parameters and consequently the difference of distribution of *O. nana* between the two bays is not determined by the physical and chemical measured parameters.

Bibliographical data concerning the water quality around Toulon Bay are relatively poor. The several existing works show markedly that the little bay is characterized by high level of eutrophication, pollutants and anthropogenic inputs contrary to the large bay (see IFREMER, 1990, 1993, 1997; CONSOLE *et al.*, 1993; DARAGON, 1994). In addition, the confined character of the little bay due to the presence of the breakwater limits the water circulation and emphasizes the level of pollution.

Concerning eutrophication, our investigations and previous studies show the higher level of eutrophication in the little bay than the large one. In 1997, P-PO_4^{3-} and P-PT reached 1.8 and 5.7 μM respectively in the little bay (DESPIAU-PUJO, submitted) and N-NO_3^- reached 0.05 μM in January 2000 (JEAN, pers. com.). In the large bay, we do not have at our disposal regular values of the concentrations of nutrients, but according to IFREMER (1990), there is no significant risk of eutrophication and phytoplankton development. In addition, there were significant differences in the concentration of chlorophyll *a* in the little bay and in the large bay. The chlorophyll *a* concentrations recorded in 1995 (JAMET *et al.*, in press) in the little bay (0.4 to 3.1 μg · l^{-1}) were much higher (10 times more in autumn and 15 times in spring) than outside. They indicate a high phytoplankton development over the whole studied period in the little bay, and particularly in

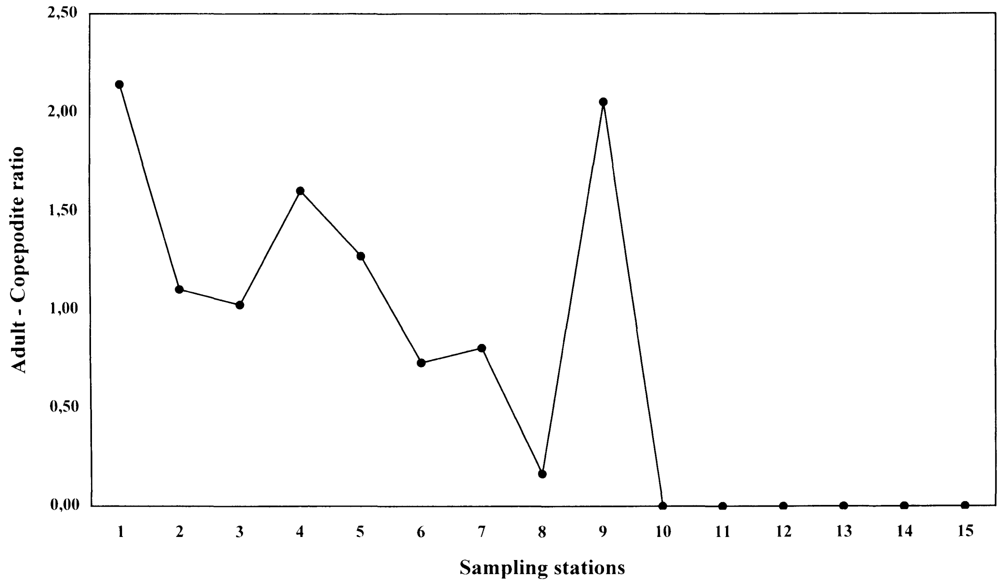

Figure 4. Adult-Copepodite ratio (adults/copepodites) of *Oithona nana* at the 15 sampling stations in Toulon Bay.

spring (corresponding phytoplankton biomass = 130 $\mu g \cdot l^{-1}$). These results were corroborated in September 1999 when the concentrations in chlorophyll *a* peaked up at 4.0 $\mu g \cdot l^{-1}$ (JEAN, *pers. com.*). JACQUES and TREGUER (1986) state that, in Mediterranean Sea, the mean chlorophyll *a* concentrations off-shore varies between 0.1 and 0.5 $\mu g \cdot l^{-1}$ and values of 1.0–1.5 $\mu g \cdot l^{-1}$ indicate a moderate phytonplankton development in the water column. Thus, according to the latter authors and to PSYLLIDOU-GIOURANOVITS (1997), the concentrations of nutrients and chlorophyll *a* recorded in the little bay of Toulon are characteristic of eutrophic waters, unlike to the large bay, which has oligotrophic waters.

For the other type of anthropogenic inputs, urban runoff enters abundantly the little bay by two rivers (Las and Eygoutier Rivers), particularly during rainfalls. This pollution is linked to suspended solids (organic compounds, hydrocarbons and heavy metals) assessed to 1800 tons $\cdot$ year^{-1}. Consequently, in this bay Lead, Mercury, Zinc, Copper and Cadmium may reached high level of concentrations as recorded by the "Réseau National d'Observation, RNO" of IFREMER (1993) in mussel watch (*i.e.* 18.7 Pb, 1.2 Hg, 330 Zn, 19.1 Cu and 2.5 Cd mg $\cdot$ kg^{-1} dry weight of mussels). PCB in mussels are also relevant. The little bay is particularly affected by the TBT used in the anti-fouling paints and its concentration in seawater varied between 50 and 60 ng $\cdot$ l^{-1} and may reached 237 ng $\cdot$ l^{-1}. At contrary, in the large bay, TBT concentrations are much lower and ranged from 0.6 to 2.6 ng $\cdot$ l^{-1}. Sediments in the little bay salt out pollutants in the water column, leading to a deterioration of the quality of water. These sediments are highly contaminated by hydrocarbons (300 to 1200 mg $\cdot$ kg^{-1}) and PCB (31 to 228 ng $\cdot$ g^{-1}). In addition, heavy metals as Zinc (93 to 264 $\mu g \cdot g^{-1}$), Lead (46 to 149 $\mu g \cdot g^{-1}$) and Copper (23 to 117 $\mu g \cdot g^{-1}$) show high concentrations in sediments. In the large bay, heavy metals may reach high values in sediments but the occurrence of an active hydrodynamism favours their dispersion in the water column, leading to much lower concentrations in sea water. Endly, the bacteriological quality of water is also considered as mediocre and chronic with coliforms blooms in the little bay and a low risk of toxic phytoplankton occurence has been find out by IFREMER in the network REPHY since 1993.

GAUDY (1971, 1972) also noted that there were few *O. nana* in the less polluted areas in the harbours of Marseille. This may be because the euryece *O. nana* can develop easily in perturbed ecosystems due to its low respiratory rate and its highly adapted metabolism (LAMPITT and GAMBLE, 1982). Other studies have also reported *O. nana* in perturbed areas. YAMAZI (1964) found that this copepod was abundant in littoral and coastal zones sampling stations located in the polluted harbour of Naples (Italy). PATRITI (1972, 1984), PATRITI *et al.* (1979) and ARFI *et al.* (1981) showed that *O. nana* was characteristic of several areas of the harbour of Marseille that were heavily polluted and in sampling stations near the sewage discharge zone at Marseille-Cortiou, where eutrophication was important. LAKKIS and ABBOUD (1976) also recorded this species in the polluted zones of the Lebanese sector in the eastern Mediterranean, but indicated that was also present in less polluted areas. Lastely, KRSINIC (1995) recorded the absolute dominance of *O. nana* (up to 73% of the total number of postnaupliar copepods) also in pelagial zones in the northern Adriatic Sea during 1989 to 1992, when there was heavy pollution due to the presence of large mucous aggregates. He noted the importance of this small copepod in remineralization in the northern Adriatic.

However, although the above studies (except for KRSINIC in 1995) indicate that *O. nana* is characteristic of perturbed ecosystems (as second or third dominant species in the zooplankton community), they do not report its dominance (first species in term of abundance) as found in the little bay of Toulon. We therefore suggest that the absolute dominance of *O. nana* in polluted areas was probably not detected because samples were taken with a standard 180–200 μm (or more) mesh Mediterranean sea plankton net (see also the closing WP-3 net according to TRANTER and FRASER, 1968). Our tests of size class filtrations have shown that most over 80 % *O. nana* adult and copepodites can pass through a 200 μm mesh filter. KRSINIC (1995) used a 51 Niskin bottle (so, there was no size selectivity in his sampling scheme) and found the absolute dominance of *O. nana* in the zooplankton community.

In conclusion, to our knowledge, no report has suggest that *O. nana* may be used as a bioindicator of polluted marine water. This small crustacean has a wide ecological tolerance to polluted waters. According to LAMPITT and GAMBLE (1982), it is an euryphagous species that can feed on little phytoplankton species and also on bacteria, protozoa and little planktonic crustacea. The metabolic and trophic capacities of *O. nana* allow to develop abundantly in polluted areas, and particularly in eutrophic systems where the zooplankton densities are generally elevated.

This first study on the distribution of *O. nana* shows clearly its large dominance in perturbed environment. The abundance of this species falls steeply outside. Our results suggest a possible utilization of this small copepod as an ideal bioindicator of polluted areas, at least in the north-west Mediterranean sea.

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