P.S.Z.N.I: Marine Ecology, 3 (2): 133–142 (1982)

ISSN 0173-9565/InterCode: MAECDR

Accepted: 4. 11. 1981

Zooplanktonic Communities of the Divergence Zone in the Northwestern Alboran Sea

JAIME RODRÍGUEZ[1], ALBERTO GARCÍA[2] & VALERIANO RODRÍGUEZ[1]

[1] Department of Ecology, Faculty of Sciences, University of Malaga, Spain.
[2] Spanish Institute of Oceanography, Coastal Center of Malaga, Spain.

With 8 figures and 3 tables

Key words: Zooplankton, communities, divergence, principal component analysis.

Abstract. Using principal component analysis, the zooplanktonic communities of the divergence zone in the northwestern sector of the Alboran Sea were studied. The study was based on 35 vertical trawls in the 200 metres superficial level. The two first components account for 65 % of the total variance. The first component is a contrast between a warm water coastal community (characterized by low specific diversity and the abundance of *Cladocera* and *Copepoda* such as *Acartia clausi, Centropages chierchiae* and *Temora stylifera*) and a community of cold subsuperficial water distinguished by high specific diversity and a low number of individuals, one of its most characteristic elements being the eggs and larval stages of the *Gonostomatidae Maurolicus muelleri*. The second component appears to be associated with an ecotone between the communities previously cited, and with a specific grouping (*Rhincalanus nasutus, Eucalanus monachus, Pseudocalanus elongatus, Temora longicornis*, etc.) resulting from the peripheral displacement of subsuperficial elements brought to the surface by the cyclonic circulation of water masses between the Atlantic current and the Spanish coast.

Problem

The Alboran Sea, as the Mediterranean zone most directly affected by the Atlantic current, is undoubtedly of great ecological interest. In spite of this, our knowledge of its planktonic community structures contains many gaps. This situation is chiefly due to the fact that our knowledge is based on the results of several oceanographic surveys whose sampling stations were widely separated. These surveys gave rise, for example, to the studies of VIVES *et al.* (1975) and ALCARAZ (1977). Also, according to our knowledge, only one study on the annual cycle of the planktonic community has been conducted in the zone (RODRÍGUEZ, in press).

The aim of this study was to obtain basic information about the zooplanktonic community structure in the northwestern sector of the Alboran Sea by using multivariate analysis. Knowledge of the existence of intense environmental gradients in this zone could be expected to facilitate the understanding of the ecological significance of each community. These gradients result from the penetration of the Atlantic current into the Mediterranean and from the existence of a divergence system between this current and the Spanish coast, which was revealed by the previous larger scale oceanographic surveys in this area (LANOIX, 1974; CANO, 1977, 1978 a and b).

Material and Methods

A study was conducted of 35 zooplankton samples obtained between the 24th and 28th July, 1975 in the area shown in Fig. 1. Vertical trawls were carried out using a HENSEN net with a 300 μm mesh. The vertical extent of trawls in relation to the total depth at these points is shown in Table 1. In addition, at 32 of the sample points, vertical profiles of temperature and salinity were made using a STD Plessey-9060.

Table 1. Characteristics of the sampling stations

Station No.	Depth of trawl (m)	Total depth (m)
1	15	21
2	70	75
3	100	263
4	100	437
5	100	618
6	70	740
9	100	640
10	100	700
11	100	442
12	100	309
13	60	94
14	45	54
15	42	50
16	100	156
17	111	400
18	103	782
19	100	920
21	100	964
22	140	820
23	100	370
24	100	202
25	60	72
26	46	52
38	60	71
39	25	31
27	50	62
28	100	131
29	100	310
30	100	550
32	100	837
33	100	491
34	100	236
35	40	45
36	70	80
37	80	85

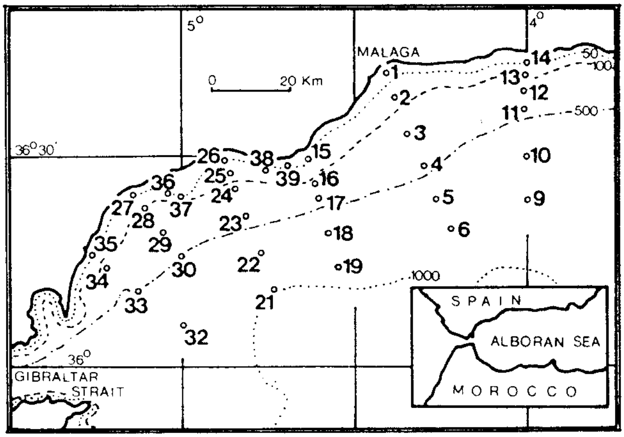

Fig. 1. Sampling stations in the study area.

The counts of the zooplankton were carried out on aliquot parts in a BOGOROV-type small cask, the results being expressed in number of individuals per cubic metre, as a function of the total length of trawls and net aperture.

To adapt the data obtained for multivariate analysis, it was decided to limit the number of species to those most frequently encountered, *i.e.* those present in a minimum of 19 of the 35 samples. Also, the logarithmic transformation of the abundance values was necessary $x \rightarrow \log(x + 1)$. From this, the interspecies correlation matrix was calculated (Table 2), to which the *principal component* analysis was applied with *varimax* rotation. This technique seems to offer the most convenient presentation of the plankton data (IBANEZ & SEGUIN, 1972).

The analysis was carried out in the Computer Centre of the University of Malaga, using a SPSS program and a Univac-1108 computer.

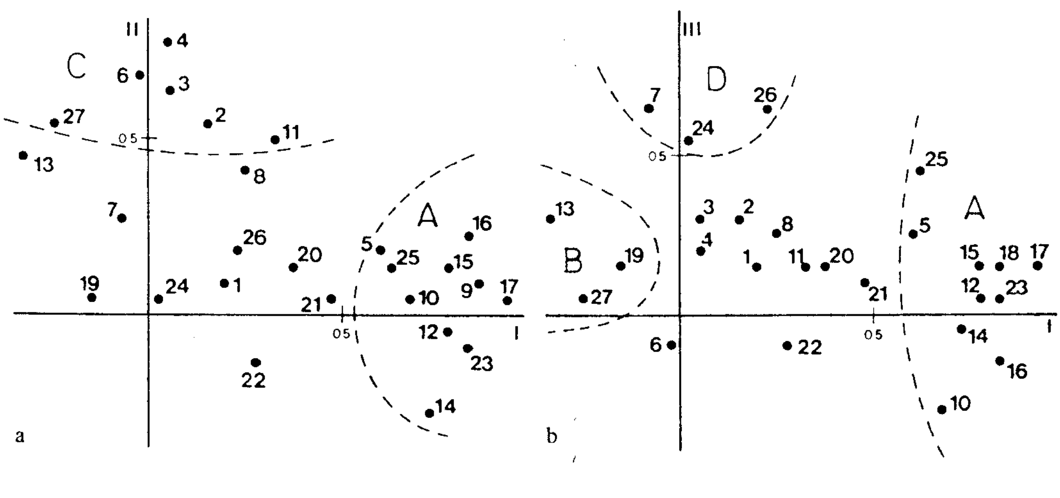

Fig. 2. Position of the species in the space defined by the components I–II (a) and I–III (b).

Table 2. Correlation matrix for the selected species

1 *Calanoides carinatus*	-										
2 *Eucalanus hyalinus*	0'39	-									
3 *Eucalanus monachus*	0'10	0'50	-								
4 *Rhincalanus nasutus*	0'08	0'61	0'68	-							
5 *Paracalanus parvus*	0'07	0'18	0'19	0'11	-						
6 *Pseudocalanus elongatus*	-0'08	0'11	0'49	0'47	0'16	-					
7 *Clausocalanus* spp.	0'09	0'23	0'41	0'29	0'21	0'19	-				
8 *Ctenocalanus vanus*	-0'22	-0'08	0'36	0'38	0'18	0'55	0'36	-			
9 *Centropages chierchiae*	-0'37	-0'05	0'15	0'27	-0'23	0'35	-0'03	0'51	-		
10 *Temora stylifera*	0'09	0'06	0'11	0'04	0'68	0'10	-0'08	0'29	-0'19	-	
11 *Temora longicornis*	-0'01	-0'23	0'06	-0'12	0'50	0'25	-0'26	0'24	-0'17	0'78	-
12 *Acartia clausi*	0'29	0'51	0'33	0'51	0'20	0'39	0'30	0'29	-0'10	0'36	0'20
13 *Oithona* spp.	0'29	0'06	0'01	-0'03	0'47	0'09	-0'06	0'27	-0'13	0'75	0'72
14 *Penilia avirrostris*	0'06	0'38	0'30	0'66	-0'34	0'16	0'32	0'26	0'34	-0'37	-0'52
15 *Evadne spinifera*	0'14	0'10	-0'14	-0'14	0'37	-0'24	-0'16	0'26	-0'16	0'62	0'41
16 *Evadne nordmanni*	0'14	0'03	0'19	0'08	0'61	0'23	0'09	0'28	-0'16	0'78	0'65
17 *Evadne tergestina*	0'19	0'31	0'17	0'27	0'32	0'08	-0'05	0'21	-0'11	0'70	0'52
18 *Podon intermedius*	0'31	0'14	0'16	0'06	0'57	-0'02	0'08	0'17	-0'38	0'80	0'61
19 *Maurolicus muelleri*	0'13	0'12	-0'01	0'06	0'53	-0'10	-0'02	0'06	-0'37	0'66	0'50
20 *Engraulis encrasicholus*	-0'09	-0'14	0'02	0'12	-0'19	0'12	0'23	0'46	0'31	-0'02	-0'18
21 *Callionymus* sp.	-0'19	-0'14	0'25	0'01	0'36	0'33	-0'04	0'21	-0'25	0'29	0'43
22 *Arnoglossus* sp.	0'35	0'29	0'08	0'04	0'45	-0'06	-0'03	-0'04	-0'17	0'60	0'51
23 *Doliolum nationalis*	-0'05	-0'17	0'06	-0'08	0'13	-0'04	-0'09	0'12	-0'05	0'43	0'32
24 *Fritillaria* spp.	0'16	0'01	-0'06	-0'05	0'42	-0'05	0'02	0'23	-0'17	0'64	0'48
25 *Muggiaea atlantica*	0'18	0'36	0'12	0'19	0'60	0'02	0'25	0'25	-0'37	0'51	0'37
26 *Abylopsis tetragona*	0'11	0'20	0'34	0'30	0'19	0'15	0'36	0'45	0'07	0'09	0'01
27 *Conchoecia* spp.	-0'06	0'21	0'32	0'49	-0'06	0'45	0'13	0'29	0'40	-0'32	-0'35
	1	2	3	4	5	6	7	8	9	10	11

Results

Through the application of this analytical technique, five factors were obtained whose *eigenvalues* were greater than one. The first component accounts for 43.4 % of the total variability and the three first components account for more than 75 % of the total variability.

Using the coefficients of the linear functions defining the components and estimated by the *eigenvectors*, the 27 variables-species were projected on the planes defined by the components I and II as well as I and III (Fig. 2, a and b). This reveals the existence of various groups of associated species, whose composition is shown in Table 3. Thus, in the most positive part of axis I are all the *Cladocera*, the siphonophore *Muggiaea atlantica* and *Copepoda* as *Acartia clausi*, *Centropages chierchiae* and *Temora stylifera*, these species being normally considered as neritic and epipelagic. In the negative part of this axis species of deep origin were found, for example the eggs and larval stages of *Maurolicus muelleri*. Over axis II, in its positive part, are grouped species normally considered of subsuperficial origin *(Rhincalanus nasutus, Eucalanus hyalinus, E. monachus)* together with others of intermediate behaviour (see Discussion). On axis III were some groups of congeneric species not differentiated in this study *(Clausocalanus, Fritillaria)* because this axis is difficult to interpret; in any case, this third component is rather less important than the other two.

-														
0'30	-													
0'32	-0'30	-												
-0'04	0'65	-0'29	-											
0'27	0'72	-0'36	0'53	-										
0'61	0'64	-0'07	0'48	0'65	-									
0'41	0'69	-0'28	0'63	0'77	0'79	-								
0'34	0'61	-0'29	0'53	0'62	0'69	0'79	-							
0'16	-0'09	0'26	0'00	-0'03	-0'06	-0'16	-0'16	-						
0'12	0'21	-0'30	0'16	0'33	0'17	0'39	0'35	-0'07	-					
0'29	0'60	-0'33	0'30	0'51	0'17	0'53	0'40	-0'26	-0'07	-				
0'33	0'26	-0'15	0'21	0'23	0'34	0'34	0'36	0'28	0'18	0'25	-			
0'31	0'62	-0'29	0'59	0'66	0'72	0'78	0'70	-0'03	0'37	0'27	0'13	-		
0'49	0'50	-0'04	0'25	0'44	0'58	0'62	0'70	-0'01	0'37	0'40	0'18	0'56	-	
0'02	0'27	0'21	0'23	0'29	0'09	0'24	0'17	0'20	0'25	0'09	-0'12	0'12	0'28	-
0'01	-0'33	0'53	-0'18	-0'24	-0'28	-0'36	-0'36	0'23	0'09	-0'48	-0'37	-0'19	-0'11	0'12
12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

The spatial distribution of the values *(factor scores)* of the two first components might contribute to the interpretation of its relative significance (Fig. 3). The first component shows a distribution similar to the abundance of zooplankton, as is illustrated by the total of *Cladocera* (Fig. 4). In turn, the zooplankton

Table 3. Composition, in decreasing order of their loadings, of the species grouping defined in Fig. 2

Group A	Group C
17. *Evadne tergestina*	4. *Rhincalanus nasutus*
23. *Doliolum nationalis*	6. *Pseudocalanus elongatus*
9. *Centropages chierchiae*	3. *Eucalanus monachus*
16. *Evadne nordmanni*	2. *Eucalanus hyalinus*
18. *Podon intermedius*	27. *Conchecia* spp.
12. *Acartia clausi*	11. *Temora longicornis*
15. *Evadne spinifera*	
14. *Penilia avirrostris*	
10. *Temora stylifera*	
25. *Muggiaea atlantica*	
5. *Paracalanus parvus*	

Group B	Group D
13. *Oithona plumifera* + *O. helgolandica*	26. *Abylopsis tetragona*
27. *Conchoecia* spp.	7. *Clausocalanus* spp.
19. *Maurolicus muelleri*	24. *Fritillaria* spp.

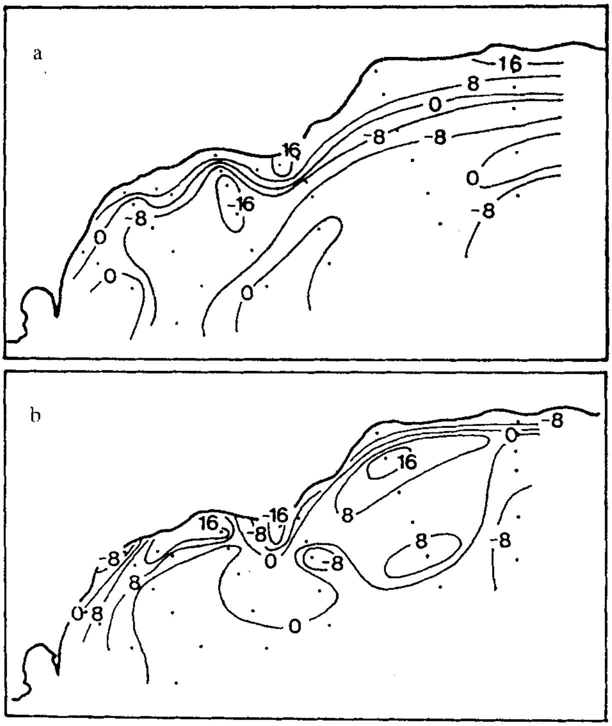

Fig. 3. Distribution of the values of the two first components (factor scores × 10) in the area studied; a: first component, b: second component.

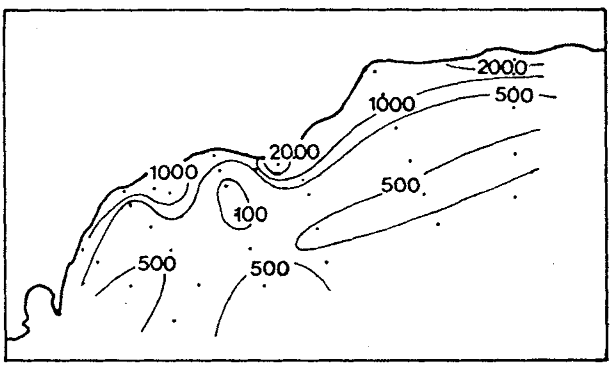

Fig. 4. Abundance of total *Cladocera*, as the most important group of the zooplankton in summer (ind. m^{-3}).

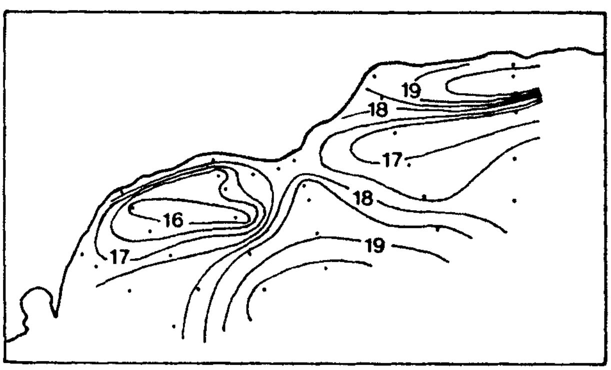

Fig. 5. Temperature distribution at 10 metres of depth (°C).

abundance is determined by the temperature distribution (Fig. 5). This abundance is markedly diminished in the cores of lower superficial temperature of the divergence system existing in this area. Precisely, the distribution of the second component appears to be associated with the periphery of these cores of divergence, especially with the contact zone between the cold water of deep origin and the warm, neritic and superficial waters.

The projection of the samples on the two first components taken from the interspecies correlation matrix, reveals the existence of two principal groups situated on opposite limbs of the axis I (Fig. 6). The samples taken from the shallower coastal water are found in the positive part of this axis. Those taken from the divergence cores are found in the negative sector. The samples which reflect the transition between these cores and the coastal waters are mostly grouped in the positive sector of axis II.

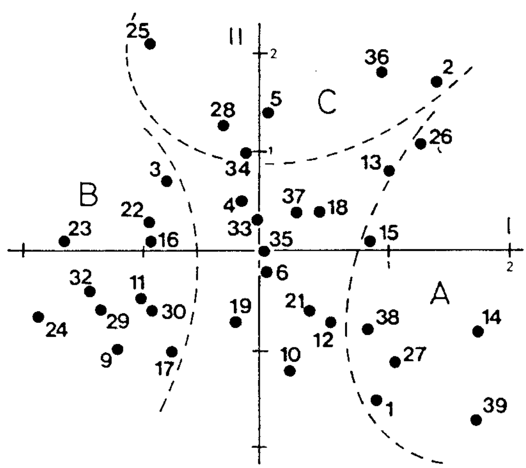

Fig. 6. Position of the sampling stations on the plane defined by the two first components.

Discussion

The results obtained with the principal component analysis illustrate the relationship between the hydrological structure of this zone and the zooplankton during the summer season.

The cyclonic circulation existing between the Atlantic current and the Spanish coast (García *et al.*, in press) gives rise to, in the superficial levels, biological communities of different structure and origin. One community, of clearly neritic and superficial character and whose most typical elements are developed during the summer (Rodríguez, in press), appears to be associated with one principal component which is responsible for more than 40% of total variance. This community is confined to the shallower waters nearest to the coast, where the highest abundance values are found. The enormous proliferation of only a few species in these waters (Valero *et al.*, 1980) is the cause of the low specific diversity characteristic of this community (García *et al.*, *op. cit.*). On the other hand, the relationship between the first component and the abundance of organisms has been mentioned by other authors (Rojas & Estrada, 1976).

In contrast, the community which occupies the divergence cores (represented by the sample stations grouped in the negative sector of axis I in Fig. 6) shows a high specific diversity (Fig. 7) with species of generally low frequency represented by a low number of individuals (*Aetideus armatus, Pleuromamma abdominalis, Pl. gracilis, Pl. borealis, Lucicutia flavicornis, Haloptilus acutifrons,* etc.), hence the majority of them was not included in the analysis. Among those that were included, typical representatives are the copepod *Oithona* and the eggs and larval stages of the gonostomatid *Maurolicus muelleri,* a mesopelagic species abundant in the Alboran Sea (JESPERSEN & TANNING, 1926) at a depth of 300 metres. As can be seen in Fig. 8, its distribution is associated with the ascent of colder deep water.

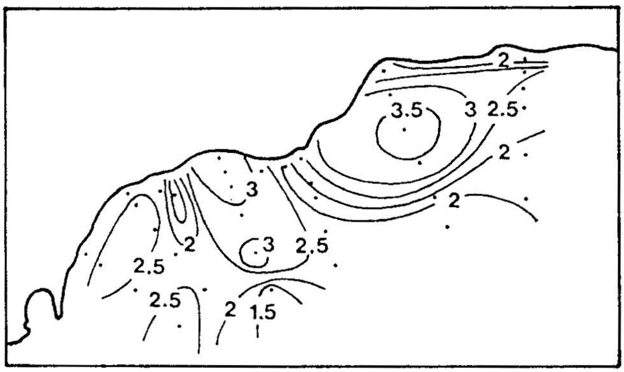

Fig. 7. Distribution of the values of specific diversity (Index of SHANNON).

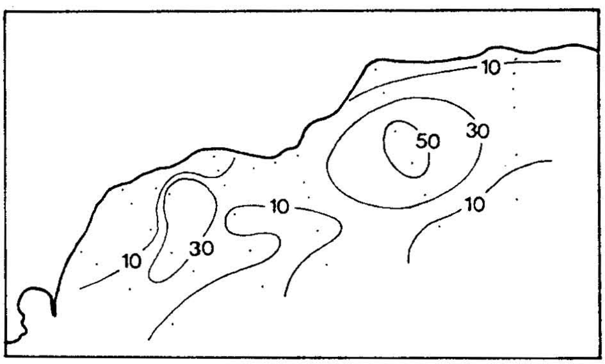

Fig. 8. Distribution of the eggs of *Maurolicus muelleri* (ind. $10\,m^{-3}$).

The community defined by the second component would seem to be linked with the areas of mixing between the cores of divergence and the coastal waters. This community is composed of species of subsuperficial origin but which adapt well to superficial environment in winter (RODRÍGUEZ, *op. cit.*), as *Rhincalanus nasutus, Eucalanus hyalinus,* etc. During this summer study, it was seen that these species had found their ideal habitat in the contact zone between different water masses. In this community, the most interesting species are *Temora longicornis* and *Pseudocalanus elongatus,* of neritic character where the superficial waters do not reach the higher temperatures found in the Mediterranean as a whole, as is the case in the nothern sectors of the Atlantic Ocean and of the Adriatic Sea (CORKETT & MCLAREN, 1978; HURE & SCOTTO DI CARLO, 1977). As has been shown in another paper (VIVES *et al.*, 1981) concerning *Pseudocalanus elongatus*, the presence of populations during summer in the Alboran Sea may be explained as having being transported into the Mediterranean in the deepest level of the Atlantic current, where they were caught by the cyclonic gyre and lifted to the surface. Here, *Pseudocalanus*, in accordance with its character, appears only where the cold water approaches the coast. This case could therefore be an example of the character of the community defined by the second component.

Summary

In the area studied it can be shown that there are two distinct communities with contrasting abundance and specific diversity. These communities are those of the warm coastal waters and of the divergence cores. Between them an ecotone could exist without any overlap of the separated communities and with a specific grouping resulting from the peripheral displacement of subsuperficial elements brought to the surface by the cyclonic circulation of water masses between the Atlantic current and the Spanish coast.

Acknowledgements

We would like to express our appreciation to the personnel of the Computer Centre of the University of Malaga for performing the calculations. Several specialists criticized this work during its execution and when conclusions were being considered. Special thanks are due to Prof. F. GARCÍA-NOVO (Dept. of Ecology, Univ. of Sevilla), Prof. F. VIVES and Dr. M. ESTRADA (Institute of Fisheries Research, Barcelona), Dr. J. CORRAL and Dr. J. PEREIRO (Spanish Institute of Oceanography, Madrid) and Prof. X. NIELL (Dept. of Ecology, Univ. of Malaga).

References

ALCARAZ, M., 1977: Cladóceros y Ostrácodos de los alrededores del Estrecho de Gibraltar en junio–julio de 1972. Res. Exp. Cient. B/O Cornide, **6:** 41–63.

CANO, N., 1977: Resultados de la campaña "Alborán-73". Bol. Inst. Esp. Oceanogr., **1:** 103–175.

– –, 1978a: Resultados de la campaña "Alborán-76". Bol. Inst. Esp. Oceanogr., **4** (2): 3–50.

– –, 1978b: Hidrología del Mar de Alborán en primavera-verano. Bol. Inst. Esp. Oceanogr., **4** (2): 51–66.

CORKETT, C. J. & I. A. MCLAREN, 1978: The biology of *Pseudocalanus*. Adv. mar. Biol., **15:** 1–231.

GARCÍA, A., J. RODRÍGUEZ, N. CANO & V. RODRÍGUEZ, in press: Hidrología y zooplankton del sector noroccidental del Mar de Alborán. Bol. Inst. Esp. Oceanogr.

HURE, J. & B. SCOTTO DI CARLO, 1977: An account of the copepod distribution of the surface-water community in the Adriatic Sea. Rapp. Comm. int. Mer. Médit., **24** (10): 133–134.

IBANEZ, F. & G. SEGUIN, 1972: Etude du cycle annuel du zooplancton d'Abidjan. Comparaison de plusieurs méthodes d'analyses multivariable. Inv. Pesq., **36** (1): 81–108.

JESPERSEN, P. & A. V. TANNING, 1926: Mediterranean *Sternoptychidae*. Rep. Dan. Oceanogr. Expd. Mediterr. 1908–1910, (A 12) 2, Biology: 59 pp., 30 Figs.

LANOIX, F., 1974: Etude hydrologique et dynamique de la Mer d'Alboran. Rapp. Tech. OTAN, Nr. 76, 39 pp.

RODRÍGUEZ, J., in press: Estudio de una comunidad planctónica nerítica en el Mar de Alborán. I.- Ciclo del zooplancton. Bol. Inst. Esp. Oceanogr.

ROJAS, B. & M. ESTRADA, 1976: El fitoplancton del área de Pimentel. Verano de 1972. Inv. Pesq., **40** (2): 463–490.

VALERO, J. A., A. CUEVAS & J. RODRÍGUEZ, 1980: Cladóceros del sector noroccidental del Mar de Alborán. Cuad. Cienc. Biol., **6–7:** 133–142.

VIVES, F., G. SANTAMARÍA & I. TREPAT, 1975: El zooplancton de los alrededores del Estrecho de Gibraltar en junio–julio de 1972. Res. Exp. Cient. B/O Cornide, **4:** 7–100.

– –, V. RODRÍGUEZ & J. RODRÍGUEZ, 1981: Sobre la presencia de *Pseudocalanus elongatus* BOECK *(Copepoda, Calanoida)* en el Mar de Alborán. Inv. Pesq., **45** (2): 337–343.