Cumacean density, biomass and productivity in the sandy bottoms of the Blanes Bay (western Mediterranean)

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Running title: Mediterranean sandy bottom cumaceans

Keywords: Cumacea, shallow waters, benthos, secondary production, NW Mediterranean

Abstract: During a study on seasonal dynamics and community structure of the sublittoral soft-bottom macroinfauna carried on from 1992 to 1997 in Blanes Bay, ten cumacean species were collected. Density and biomass of *Bodotria pulchella, Iphinoe douniae, Pseudocuma longicorne* and *Pseudocuma simile* (the most frequent species) were calculated based on fortnightly samples, from March to September 1992 . *Bodotria pulchella* showed the highest mean density (47.7 ind. m^{-2}), while its mean biomass (AFDW) was 1.24 mg m^{-2}. *Iphinoe douniae* showed 35.3 ind. m^{-2} on average, but its mean biomass was higher than in *B. pulchella* (2.01 mg m^{-2}) due to its large size. The density and biomass trends varied independently among the four species. However, the corresponding trends for the whole population throughout the five years of study showed higher mean values of abundance and biomass during late spring / early summer. According to an empirical model, the secondary production for the four species ranged between 2.75 and 12.93 mg m^{-2} yr^{-1}, while the corresponding P/B ratio ranged between 7.1 and 10.8. Although high, these values do not differ from those previously reported for other suprabenthic crustacean populations.

Résumé: *Densité, biomasse et productivité des cumacés dans les fonds sablonneux de la baie de Blanes (Méditerranée occidentale).* Pendant une étude sur la dynamique saisonnière et la structure de communauté de la macroinfaune des fonds meubles infralittorals conduit entre 1992 et 1997 dans la Baie de Blanes, dix espèces de cumacés ont été recueillies Entre mars et septembre 1992, les échantillons ont été recueillies deux fois par mois et on a calculé la densité et la biomasse de *Bodotria pulchella, Iphinoe douniae, Pseudocuma longicorne* et de *Pseudocuma simile* (les espèces les plus fréquentes). *Bodotria pulchella* a montré la plus haute densité moyenne (47,7 ind. m^{-2}), pendant que sa biomasse moyenne (AFDW) était 1,24 mg m^{-2}. *Iphinoe douniae* a montré 35.3 ind. m^{-2} en moyenne, mais sa biomasse moyenne était plus haute que dans *B. pulchella* (2,01 mg m^{-2}) en raison de sa plus grande taille. La densité et les tendances de biomasse variées de façon indépendante parmi les quatre espèces. Cependant, les tendances correspondantes pour la population entière le long des cinq ans d'étude ont montré de plus hautes valeurs moyennes d'abondance et de biomasse à la fin du printemps / début de l'été. Selon un modèle empirique, la production secondaire pour les quatre espèces a varié entre 2,75 et 12,93 mg m^{-2} a^{-1}, pendant que le rapport P/B correspondant a varié entre 7,1 et 10,8. Bien que haut, ces valeurs ne diffèrent pas des auparavant rapportés pour d'autres populations de crustacés suprabenthiques.

Introduction

Estimates of biomass and secondary production are a basic tool allowing understanding the energy flow in marine ecosystems. Although extensively studied for some sublittoral infaunal taxa such as polychaetes (Brey, 1990; Martin & Grémare, 1997; Sardá et al., 2000) or molluscs (Howe et al., 1988; Brey, 1990; Maurer et al., 1992), other groups have received little attention, being the cumaceans probably among the less studied. Cumaceans play an important ecosystem role, as they are common preys for other marine organisms such as small and juvenile fishes, cephalopods and crustaceans (Longhurst, 1957; Karpov & Cailliet, 1979; Léauté, 1986; Mazzola et al., 1999 among others). In organically enriched environments, cumaceans may reach high densities (up to more than 80,000 ind. m^{-2} in Moore et al., 2007), being even a relevant component of grey whales' diet (Fadeev, 2003; Moore et al., 2007). In intertidal mudflats, where densities may be higher than 30,000 ind. m^{-2}, cumaceans are also one of the main preys for littoral birds (Sutherland et al., 2000).

Notwithstanding, little is known about density and biomass trends for the cumacean assemblages in the Mediterranean Sea, where maximum densities observed (Massé, 1972; Corbera & Cardell, 1995; Sardá et al., 1999) are about two orders of magnitude lower than the above mentioned abundances. Among the more than 1500 species known to date, secondary production estimates have been documented only for three species: *Diastylis rathkei* (Krøyer, 1841), *Leucon longirostris* Sars, 1871 and *Cumopsis goodsir* (Van Beneden, 1861)(Rachor et al., 1982; Cartes & Sorbe, 1999; Corbera et al., 2000; respectively).

Within the framework of a more general study on the structure and dynamics of the soft-bottom communities (Pinedo et al., 1996; Sardà et al., 1999), the cumacean populations of Blanes Bay were sampled seasonally from 1992 to 1997. The present paper analyses these samples and provides data on the density and biomass trends for the cumacean species living in shallow-water sandy bottoms of the Bay, as well as the first estimates of secondary production and P/B ratios for the four most frequent species, *Bodotria pulchella* (Sars 1878), *Iphinoe douniae* Ledoyer 1965, *Pseudocuma longicorne* (Bate 1858) and *Pseudocuma simile* Sars 1900.

Material and Methods

The seasonal dynamics of the benthic macroinfauna inhabiting a 15 m deep station (41°40.6'N 2°48.2'E) in the Bay of Blanes was monitored from March 1992 to March 1997. The station was located between the Blanes harbour and the mouth of the Tordera River. The obtained dataset has been included as one of the 44 datasets collected, harmonized and integrated into the relational access MacroBen database on softbottom macrobenthic fauna from all European Seas (Somerfield et al., 2009; Van der Bergue, 2009).

The sampling periodicity (fortnightly to bimonthly) varied according to years and seasons. Following preliminary results of the first two years of the study, sampling efforts were concentrated during the main recruitment events, and kept distanced during the rest of the year; however, as a general pattern, the maximum interval between two sampling days was two months. Cumacean data presented in this paper correspond to two different periods: a) the dynamics of the entire cumacean population from March

1992 to March 1997, and b) a detailed study done during the period March to September 1992 when samples were collected fortnightly.

The sediment of the station was composed by fine sand with an average grain size of between 148 and 169 µm, a silt content of 2.19% and an organic content ranging from 0.7 to 1.4% (Sardá et al., 1999). We used a van Veen grab (600 cm^2 in surface, able to penetrate about 12 cm into the sediment). Two replicates were collected on each sampling date. Samples were sieved trough a 500 µm mesh size, fixed in formaldehyde and stained with rose Bengal.

Cumacean species abundance for the series March 1992-March 1997 is shown as the means of the sample days. To transform the data into series with equal number of equally spaced data, the interpolation method of Fox and Brown (1965) was used. The time interval chosen for the regularization procedure was two months as this was the maximum period of delay between sampling days. Using this time-regularized series, the general annual patterns (pooling the five year series of data) were obtained for abundance and biomass of the whole assemblages as well as for the key species.

Secondary production for the four most important cumacean species was obtained from March to September 1992. After identification at species level, selected species were measured with and ocular micrometer using a stereomicroscope. Carapace length (CL, µm) was measured from the tip of pseudorostrum to the posterior dorsal edge of the carapace. Biomass (as ash free dry weight, AFDW, µg) was obtained as the difference between dry weight (24 h at 70°C) and the ash weight (5 h at 450°C). To estimate biomass and secondary production for the whole populations of the four most abundant species, allometric relationships (as power functions) were established between CL and AFDW. Secondary production was then estimated following the empirical model of Brey (1990) for macrobenthic crustaceans according to:

$$\log P = -0.614 + 1.0221 \log B - 0.360 \log W_j$$

where P is the annual production, B the mean annual biomass and W_j the mean individual weight. For the purposes of Brey's formula, we used the mean biomass of the studied period as an estimate of B, despite we realize this could overestimate final production. In fact, the during the non-sampled months, cumacean densities often tend to be lower than in spring and summer (Corbera et al., 2000).

Results

Total abundance samples exhibited a nearly unchanging pattern between years (Fig. 1). A peak characterized this seasonal pattern during late spring-early summer, then a sharp decrease throughout the rest of summer, and the maintenance of low densities during autumn and winter, where finally abundance rose again. The maximum density for the whole cumacean assemblage occurred in August 1995 (333 ind. m^{-2}). Their general trend, based on the regularized data pooled by month for all year studied, can be seen in inset graph of Figure 1.

During the studied period, ten cumacean species belonging to three families were collected (Table 1): Bodotriidae (7 species), Pseudocumatidae (2 species) and Nannastacidae (1 species). *Bodotria pulchella* and *Iphinoe douniae* were the most frequent (100%) and abundant species, followed by *Pseudocuma longicorne* and *P. simile*.

When we concentrated our effort during the first year, the abundance peak tended to be much clearly observed in summer and a small peak was noticed in late winter/early spring (Fig. 2). *Bodotria pulchella* showed the highest mean density, followed by *I. douniae*, *Pseudocuma longicorne* and *P. simile* (Table 2). For these species, CL was always positively and significantly related to AFDW (Fig. 3).

Biomass mirrored density trends, being higher in August (9.6 mg AFDW m^{-2}). However, the late winter/early spring peak, was less marked than for density (Fig. 2B). *Iphinoe douniae* showed the highest mean biomass (1.8±1.6 mg AFDW m^{-2}), as its density, lower than that of *B. pulchella* were compensated by its larger size (Table 2).

The secondary production ranged between less than 3 and about 13 mg AFDW m^{-2} yr^{-1} (corresponding to *Pseudocuma simile* and *Iphinoe douniae*, respectively). In turn, the P/B ratio ranged between 7 and a few less than 11 (corresponding to *I. douniae* and *Pseudocuma longicorne,* respectively) (Table 2).

Discussion

The cumacean assemblage found at 15 m deep in Blanes Bay represented about 1% (in terms of abundance) of the whole benthic community, which was dominated mainly by polychaetes and molluscs (see Sardá et al., 1999). The species diversity resembled those previously recorded at comparable depths along the western Mediterranean (Massé, 1972; Corbera & Cardell, 1995). However, there were small differences in species composition (i.e. represented by different congener species), as well as in their relative contributions, both in terms of density and biomass. Although the cumacean assemblage showed its higher density in August during 1992 (i.e. coinciding with the productivity analysis), the highest annual densities most commonly occurred in June, as seen in the following years.

Pseudocuma longicorne, Iphinoe douniae and *Cumopsis longipes* (Dohrn, 1869) were reported as dominant in the 5 m deep sandy bottoms of Prado beach, French Mediterranean coast near Marseille (Massé, 1972). *Bodotria pulchella, P. longicorne, P. simile* and *Iphinoe armata* Ledoyer 1965 were dominant in sandy bottoms near Barcelona (Catalonia, Spain), from 5 to 10 m deep (Corbera & Cardell, 1995) and a very similar assemblage (excluding *P. longicorne*) dominated at 10 m deep in a shore North to Civitavecchia, Italy (Scipione et al., 2005). In these relatively similar environments, the replacement by congeners may be either related to differences in the regional pull of species or with small changes in sediment granulometry, one of the most important factors in structuring cumacean assemblages (Wieser, 1959; Martin et al., 2010).

Cumacean assemblages showed a wide rage of densities depending on the world region, tending to be higher in higher latitudes or in more eutrophic environments (Dayton & Oliver, 1977). As the Mediterranean is mostly an oligotrophic sea, the so far reported cumacean densities there (Table 3) are considerably lower than the maxima reported worldwide (>35,000 ind. m^{-2}; Gnewuch & Croker, 1973; Fadeev, 2003; Moore et al., 2007). Maximum densities known in the Mediterranean (2-3 orders of magnitude lower that the world maxima) occurred in two areas anthropogenically enriched with high organic matter contents in the sediments (from 600 to 1100 ind. m^{-2}; Table 3). In turn, the more typical, oligotrophic sandy bottoms support even low-dense assemblages (i.e. less than 70 ind. m^{-2}, Table 3). In Blanes Bay, the cumacean densities may reach up to five times higher densities (Table 3), this being likely related to the proximity of the Tordera River, which runoff may provide supplementary food. A similar situation was previously reported for the Alfacs Bay (Palacín et al., 1991), where the combination of enclosure and continental runoffs lead the cumacean assemblages to reach densities higher than 100 ind. m^{-2} (Table 3).

Cumacean biomasses, in turn, have been scarcely reported, often expressed in different units (wet weight, WW; dry weight, DW; or AFDW) and based on different sampling methodologies (e.g. dredges, sledges) and mesh sizes. This lack of comparability was partly solved by weight-to-weight conversion factors, such as those estimated for *Eudorella pacifica* (Lie, 1968) and *Diastylis goodsiri* (Wacasey & Atkinson, 1987) and compiled for *Diastylis rathkei* (Rumohr et al., 1987). However, these factors must be used with care, as they show relevant intra- and inter-specific differences. The AFDW-WW ratio for *Diastylis rathkei* differed among development instars and sizes, although the average at the German Bight was comparable to that of *Eudorella pacifica* in Puget Sound (Table 4A). On the other hand, *Cumopsis goodsir* had similar AFDW-DW ratios in shallow waters of the Catalan Sea that estimated for *E. pacifica* in Puget Sound, while *Leucon longirostris* showed a twice-lower ratio in the bathyal slope of the Catalan Sea (Table 4A). This last value is also clearly lower than those reported for *Diastylis goodsir* in the Arctic and for *D. rathkei* in the Baltic Sea (Table 4A). Accordingly, this variability may be related either to the mean size of each species, to the calcification degree of its exoskeleton or to a combination of both factors.

Although maximum cumacean biomasses recorded to date are higher than14 g m^{-2} (as AFDW and using Lie (1968)'s conversion factors when required), the following ones are considerably far from this value (from a few less than 3 g m^{-2} to about 0.7 g m^{-2}), but the most habitual values are frequently much lower (Table 4B). As for the density, the Mediterranean cumaceans had biomasses some degrees of magnitude lower than the Atlantic ones. For instance, a mono-specific assemblage of *Cumopsis goodsir*

showed a maximum of less than 0.2 mg m^{-2} in an exposed dissipative sandy beach in the Catalan Sea, a value clearly lower than that here reported for the Blanes Bay assemblage (Table 4B). In this case, the divergence may be caused by the differences in habitat (dissipative beach vs. open bay with riverine inputs, respectively).

Secondary production, like biomass, has been only estimated for a few cumacean species and showed contrasting values between regions (Table 4C). Both morphological and ecological inter-specific differences may also be among the main reasons explaining this variability. Differences in density and biomass reflecting distinct environmental conditions have been suggested as possible factors affecting annual production in the case of a *Cumopsis goodsir* assemblage from the Catalan Sea (Corbera et al., 2000). But, again, sampling methodology may cause major bias in the estimates, as cumaceans live in the water-sediment interface and the different gears (e.g. dredges, sledges) may capture different parts of a same population (Table 4C). Our secondary production estimates enlarge considerably the available information for cumaceans and prove the existence of differences between species within the same assemblage. They are higher than the previous known for the Mediterranean (Cartes & Sorbe, 1999; Corbera et al., 2000), but much lower than those observed in Baltic and North Seas (Rachor et al., 1982). These differences could be related to the differences in habitat (viz. food availability, granulometry, depth) and sampling methodologies. Conversely, the P/B ratios were higher for the Mediterranean species (including our results) than for the Atlantic and Baltic populations of *D. rathkei* (Table 4C). In this case, the divergence may be considered as a confirmation of the different biology of the cumaceans from the assemblages of both geographical areas.

In summary, Mediterranean sandy bottoms harbour cumacean assemblages with a relatively low number of species. Density and biomass in these assemblages are lower than in the corresponding ones inhabiting similar bottoms in other seas. However, the proximity of a mouth river in Blanes Bay may supply the nearby cumacean assemblages with additional food source, this contributing to explain the higher values of both parameters with respect to other Mediterranean areas. Our results also points on the strict necessity of increasing the available biomass estimates for the cumacean assemblages (particularly including more species having distinct sizes and degrees of calcification), before being able to use conversion factors satisfactorily. Therefore, further studies are required to compare the productivity of different cumacean assemblages from different geographical areas, in order to better understand their trophic role within the different compartments of the Benthic Boundary Layer.

Acknowledgements

The present paper is a contribution of DM to the Consolidated Research Group 2009SRG665 of the "Generalitat de Catalunya".

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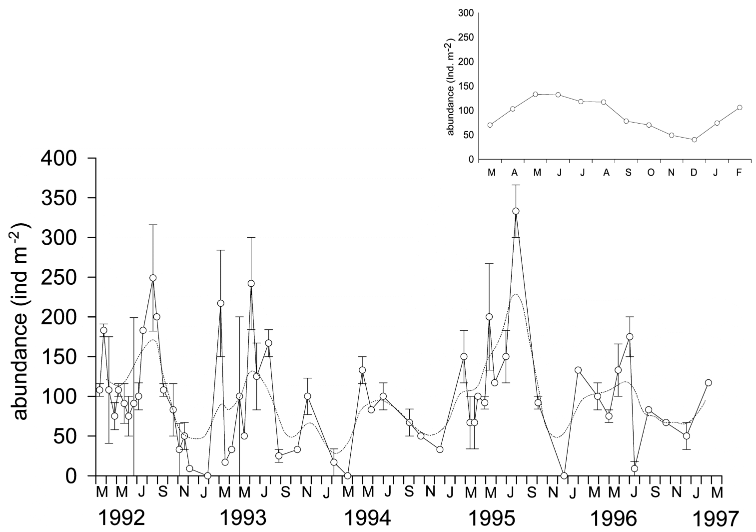

Figure 1. Abundance (straight line) and regularized abundance following interpolation method of Fox and Brown (doted line) data for the cumacean assemblage inhabiting soft-bottom environments of the Bay of Blanes (bottom graph) of the two macroinfaunal facies studied in the bay of Blanes. Annual pattern, pooling the regularizated five-year series of data is shown in the inset of the figure.

Figure 1. L'abondance (la ligne droite) et l'abondance régularisée suite à la méthode d'interpolation de Fox et Brown (ligne de points) pour l'assemblage de cumacés habitant des environnements du fond meuble de la baie de Blanes (le graphique de fond) de deux facies macroinfaunales étudié dans la baie de Blanes. Le model annuel, en mettant la série de données régularisées de cinq années en commun, est montré dans l'encart de la figure.

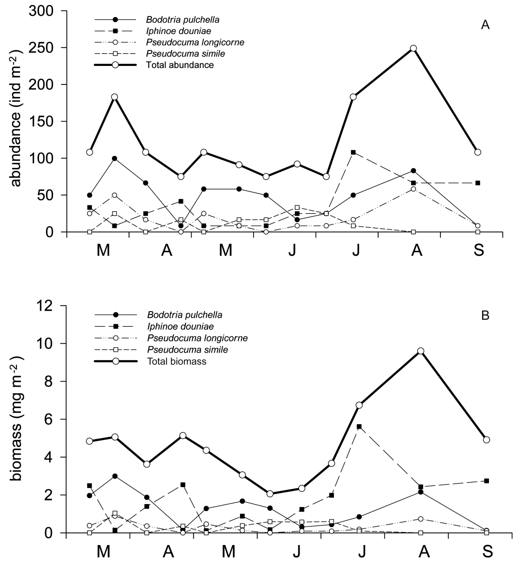

Figure 2. Changes in density (A, ind. m^{-2}) and biomass (B, mg AFDW m^{-2}) of the Blanes Bay cumacean assemblage from March to September 1992.

Figure 2. Evolution de la densité (A, ind. m^{-2}) et la biomasse (B, mg AFDW m^{-2}) dans l'assemblage de cumacés de la baie de Blanes du mars au septembre de 1992.

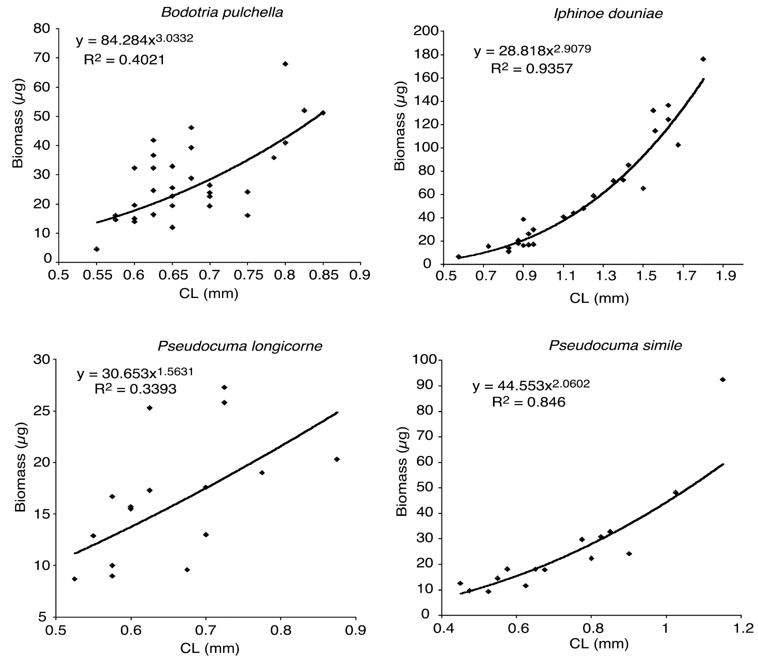

Figure 3. Relationship between biomass as ash free dry weight (AFDW) and carapace length (CL) for the four most abundant cumacean species of the sandy bottoms of Blanes Bay.

Figure 3. Le rapport entre la biomasse (poids sec sans cendres) et la longueur de carapace (CL) pour les quatre espèces de cumacés les plus abondantes des fonds sablonneux de la baie de Blanes.

Table 1. Cumacean species collected in Blanes Bay during the studied period. F: frequency of occurrence; A: total number of individuals collected.

Tableau 1. Espèces de cumacés récoltés dans la baie de Blanes pendant la période étudiée. F : fréquence d'occurrence; A: le nombre total d'individus récoltés.

Species	F (%)	A
Family Bodotriidae		
Bodotria pulchella (Sars, 1878)	100	70
Bodotria arenosa mediterranea (Steuer, 1936)	16.7	2
Iphinoe crassipes Hansen, 1895	8.3	3
Iphinoe douniae Ledoyer, 1965	100	51
Iphinoe maculata Ledoyer, 1965	8.3	2
Iphinoe tenella Sars, 1878	8.3	2
Eocuma ferox (Fischer, 1878)	8.3	1
Family Nannastacidae		
Cumella limicola Sars, 1879	41.7	6
Family Pseudocumatidae		
Pseudocuma longicorne (Bate, 1858)	83.3	27
Pseudocuma simile Sars, 1900	58.3	17

Table 2. Mean density (D, ind. m^{-2}), mean biomass (B, mg m^{-2}), mean individual weigh (W_j, mg) and secondary production (P, mg AFDW m^{-2} y^{-1}) for the four most frequent cumacean species in Blanes Bay from March to September 1992.

Tableau 2. Densité moyenne (D, ind. m^{-2}), biomasse moyenne (B, mg m^{-2}), poids moyen individuel (Wj, mg) et production secondaire (P, mg AFDW m^{-2} y^{-1}) pour les quatre espèces de cumacés les plus fréquentes dans la baie de Blanes du mars au septembre de 1992.

Species	D	B	W_j	P	P/B
Bodotria pulchella	47.7±28.8	1.26±0.91	0.029±0.014	11.37	9.0
Iphinoe douniae	35.3±30.9	1.81±1.55	0.057±0.047	12.93	7.1
Pseudocuma longicorne	18.7±18.4	0.28±0.29	0.016±0.006	3.06	10.8
Pseudocuma simile	11.8±11.9	0.30±0.34	0.026±0.021	2.75	9.1

Table 3. Cumacean densities (D, ind. m^{-2}) reported from the Mediterranean Sea, including the medium grain size (mgs) and percentages of silt and organic matter (OM) in sediments.

Tableau 3. A. Densités des cumacés (D, ind. m^{-2}) rapportés pour la Méditerranée, avec la grandeur moyenne des grains de sable (mgs) et les pourcentages de vase (silt) et de matière organique (OM) dans les sédiments.

A Locality	Depth (m)	mgs (µm)	Silt (%)	OM (%)	D	References
Prado Bay, Gulf of Lyons, France	1.5	120-130			1097	Massé, 1971a
Off Barcelona, Catalan Sea, Spain	53	–	>80	7.4	612	Corbera & Cardell, 1995
Blanes Bay, Catalan Sea, Spain	15	148-169		0.7-1.4	75-333	This study
Prado Bay, Gulf of Lyons, France	5	103-117		1	193	Massé, 1971a
Alfacs Bay, Catalan Sea, Spain	0.5-3	–	≤0.07	0.6-0.8	162	Palacin et al., 1991
Badalona Beach, Catalan Sea, Spain	5-10	262-425		0.4-0.7	45-65	Corbera & Cardell, 1995
Verdon Bay, Gulf of Lyons, France	9	125		0.89	53	Massé, 1971b
Tyrrhenian Sea, Italy	10		1.55	–	26	Scipione et al., 2005
Creixell Beach, Catalan Sea, Spain	0.5-3.5	185	<0.5	–	9	Corbera et al., 2000

Table 4. A. AFDV/WW and AFDW/DW ratios reported for different cumacean species and locations; data between brackets are ranges. B. Known reports of cumacean biomasses. C. Previously known production (mg AFDW m^{-2} yr^{-1}) and P/B ratio estimates for cumacean species. Type of sampling (TS): 1, dredge; 2, sledge.

Tableau 4. A. Rapport AFDV/WW et AFDW/DW pour quelques espèces de cumacés et ses localisations ; les données entre parenthèse correspond aux ranges. B. Rapports connus de biomasses des cumacés. C. Production auparavant connue (mg AFDW m^{-2} a^{-1}) et rapport P/B estime pour quelques espèces de cumacés. Type d'échantillonnage (TS): 1, drague; 2, traîneau.

A Species	Locality	AFDW/WW ratio	AFDW/DW ratio	References
Diastylis rathkei	German Bight	0.14 (0.12-0.28)		Rachor et al. (1982)
	Baltic Sea		0.57	Rumohr et al. (1987)
Diastylis goodsir	Arctic Sea		0.44	Wacasey & Atkinson (1987)
Eudorella pacifica	Pugget Sound	0.124	0.73	Lie (1968)
Cumopsis goodsir	Catalan Sea (shallow waters)		0.69	Corbera et al. (2000)
Leucon longirostris	Catalan Sea (bathyal slope)		0.31	Cartes & Sorbe (1999)

B	Location	Biomass (mg m^{-2})	References
	Sea of Okhotsk	14,238	Fadeev (2003)
	Danube River	2,760	Popescu-Marinescu (1983)
	Caspian Sea	1212	Bagheri & Abd Almulaki (2004)
	German Bight	710	Rachor et al. (1982)
	USA Atlantic shelf	<63	Wigley & Theroux (1981)
	Catalan Sea	0.112	Corbera et al. (2000)
	Blanes Bay	9.6	This paper

C Species	TS	Location	Depth (m)	Method	Production	P/B	References
Diastylis rathkei	1	North Sea	23	Crisp	4200	3.2	Rachor et al., 1982
	1	Baltic Sea	17-24	Crisp	2500	2.7	
Leucon longirostris	2	Mediterranean Sea	506-601	Brey	0.179	6.95	Cartes & Sorbe, 1999
Cumopsis goodsir	2	Mediterranean Sea	0.5-3.5	Hynes	0.288	7.79	Corbera et al., 2000
				Brey	0.348	9.18	Corbera et al., 2000