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Changes in the dynamics of shallow sandy-bottom assemblages due to sand extraction in the Catalan Western Mediterranean Sea

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Coarse to fine-sand sediments characterize shallow sublittoral soft bottoms in the Northwestern Mediterranean Sea. Within the framework of a wider research project on the littoral ecosystem of the Bay of Blanes (Catalan coast), the dynamics of shallow soft-bottom macroinfaunal assemblages have been followed since March 1992. These assemblages exhibited a highly predictive annual cycle. Abundance and biomass rose sharply during spring, followed by a striking drop through summer, and reaching the lowest values during winter. These cycles were consistent with the temporal variation in several key species. During the summer and autumn of 1994, shallow soft bottoms (10 to 30 m depth) off the Tordera River were dredged for beach nourishment. Recolonization in these dredged habitats was fast, and no changes in seasonal trends were detected after dredging. However, density values rose sharply during the following spring and autumn with exceptionally large numbers of *Ditrupa arietina*, *Spisula subtruncata*, and *Branchiostoma lanceolatum*. Dredging activities also led to rapid increases in biomass values, which were significantly higher than those obtained before dredging. After two years, densities were back to normal but biomasses were still high. Other species, such as the filter-feeder *Callista chione* and the carnivorous polychaetes *Protodorvillea kefersteini* and *Glycera* spp., were still clearly reduced after two years, suggesting that a longer period is needed to restructure dredged bottoms to their initial situation. Dredged habitats supported artisanal bivalve fisheries in the harbour of Blanes. The official catch data of bivalves (mainly *C. chione*, *Acanthocardia aculeata*, *Donax trunculus*, and *D. variegatus*) showed a decreasing yield since the end of dredging.

Key words: benthic community impacts, bivalve fisheries, dredging, NW Mediterranean.

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Introduction

Tourist development in the Western Mediterranean is highly dependent on beach management; the beach is undoubtedly the main asset of a resort. Natural beach processes have continued to mould the shore, but because beaches are attractive for a wide variety of recreational purposes, their natural equilibrium profile of erosion and accretion has often been disturbed by the establishment of coastal towns nearby, and corrective action is usually needed. In many situations, beach nourishment is a desirable method of beach protection and nearly always preferable to other structural methods (Clark, 1983). Offshore sand resources (not related to the reserves of beach areas) are usually employed. In these cases, the avoidance of vital areas and/or sensitive coastal ecosystems, as well as the prevention of excess siltation, are the basic protective environmental measures required. However, sand extraction for beach nourishment often leads to a complete defaunation of the benthic community. When benthic recolonization after dredging is evaluated (Kaplan *et al.*, 1975; Bonsdorff, 1980, 1983; Hily, 1983; Lopez-Jamar and Mejuto, 1988; Manzanera *et al.*, 1996; Van Dalfsen and Essink, 1997; Newell *et al.*, 1998; Van Dalfsen *et al.*, 2000), the patterns of succession in these communities,

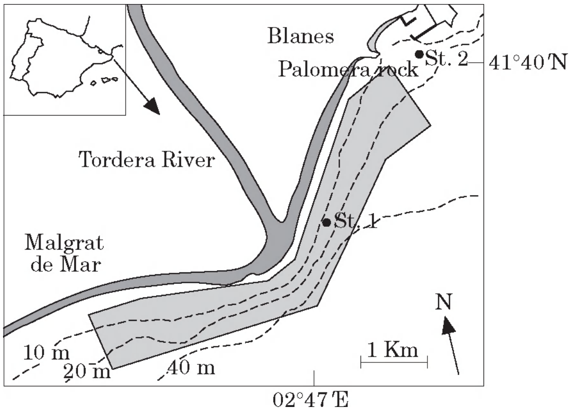

Figure 1. Map of the delta front of the Tordera River showing the location of sampling sites (St. 1 and 2) and the area from which sand was taken by suction dredge (shaded).

including the time needed to achieve pre-dredging indices, and their consequences for the ecosystem food web, are the main processes to be explained.

During summer and autumn of 1994, an area of almost 150 ha was dredged along the shore off the Tordera River. Large quantities of medium to coarse sand were used for beach nourishment of several tourist resorts south of the river mouth (the Maresme region). Dredging activities ceased at the end of November 1994. The benthic community inhabiting these sand deposits had been monitored in the past and these data could be used to identify trends and changes in the dynamics of the benthos following dredging activities using a before-after-control-impact design (Stewart-Oaten *et al.*, 1986). The recolonization pattern was followed for almost two years after the end of dredging and allowed us to make a comparison with the temporal variation in another assemblage that was not influenced directly.

The dredged sand bank supported artisanal bivalve fisheries of six species (*Callista chione*, *Acanthocardia aculeata*, *Chamelea gallina*, *Venerupis decussata*, *Donax trunculus*, and *Donax variegatus*). The fleet (four boats) was moored at the Blanes harbour, and official catch data of bivalves during the last decade were obtained. Our aim is: (a) to analyse the environmental impact of the dredging activities on the local benthic communities; (b) to analyse the effect on the local artisanal bivalve fisheries; and (c) to describe the recovery process.

Material and methods

Nourishment sand was dredged at depths between 10 and 30 m in the wave-dominated delta front of the Tordera River (Fig. 1). East of the delta, the front runs from the mouth of the river to the Palomera rock, an isolated rock that divides the beach of Blanes into two parts. The seabed consists of coarse to medium-sand sediments from 0 to 28 m depth, followed by a clear narrow fringe of fine sand sediments between 28 and 30 m, the prodelta facies. Beyond the fringe, coarse relict sea sediments occur. Further east, off downtown Blanes, deltaic sediments are replaced by fine-sand sediments. To the west, the Delta front runs from the mouth of the river to the town of Malgrat de Mar. The slope is less pronounced and the sediments consist basically of medium-sand deposits up to 20 m depth, followed by fine- to very-fine sediments further down.

The dynamics of the 15 m deep, sandy-bottom macroinfaunal assemblages of the Bay of Blanes have been followed at two stations (Fig. 1) since March 1992 (Duarte, 1996). Station 1 was located east of the mouth of the Tordera River, in the area affected by the suction dredge. Station 2 was located in front of the town of Blanes, 500 m east of the dredging zone, and may have suffered only indirect influences by sediment resuspension. These stations are characterized by a macrofaunal composition similar to the characteristic sublittoral coarse to fine-sand habitats of the Northwestern Mediterranean region (Pérès and Picard, 1964). Information on the seasonal pattern and regulating controls of the Bay before dredging have been presented for meiobenthos (Gracia *et al.*, 1996), and macrobenthos (Pinedo *et al.*, 1996, 1997; Sardá *et al.*, 2000), allowing the selection of the macroinfaunal key species, as well as the description of their seasonal dynamics.

Sampling periodicity varied according to year and season. Both stations were sampled every two weeks from March 1992 to August 1993 to elucidate the main seasonal dynamics (Sardá *et al.*, 1995). Subsequently, sampling was concentrated during the recruitment events from March to July (monthly sampling), while during the rest of the year bimonthly sampling was carried out. At station 2, sampling has been carried out since March 1992 to the present without interruption. At station 1, data collection was stopped after two years. Dredging activities started in summer 1994 and ceased at the end of November 1994. Starting in December 1994, the sampling procedure was resumed. Thus, recovery data for this station are available for almost two years.

On each sampling date, two (600 cm^{-2}) Van Veen grab samples were obtained at each station. The grab penetrated on average to 15 cm depth at station 1 and to 12 cm at station 2, with the difference depending on sediment compactness. The grab samples revealed no biogenic structures on the bottom, indicating the absence of large burrowing organisms. Small subsamples (around 25 cm^{-2}) were taken from each grab using PVC cores for determination of the organic content and granulometric composition. Organic content of dry sediment was estimated as the loss of weight after ashing. Sediment was submitted to a standard dry-sieving procedure (Wentworth, 1972) for granulometrical analysis.

Table 1. Regressions used to convert length or width (mm) to biomass (mg). N is the number of data points.

	Regression	r^2	N
Maximum tube diameter (a)			
Owenia fusiformis (Pol)	$0.8434\ (a)^{2.177}$	0.85	81
Diameter of tube aperture (b)			
Ditrupa arietina (Pol)	$0.4522\ (b)^{3.992}$	0.88	34
Shell Width (c)			
Callista chione (Biv)	$0.0210\ (c)^{2.687}$	0.95	24
Chamelea gallina (Biv)	$0.0052\ (c)^{3.153}$	0.95	19
Dosinia lupinus (Biv)	$0.0210\ (c)^{2.477}$	0.89	33
Lucinella divaricata (Biv)	$0.0090\ (c)^{3.199}$	0.85	57
Spisula subtruncata (Biv)	$0.0099\ (c)^{2.937}$	0.93	37
Tellina pulchella (Biv)	$0.0090\ (c)^{2.617}$	0.95	20
Thracia papiracea (Biv)	$0.0249\ (c)^{2.208}$	0.86	20
Length between the rostrum and the atriopore (d)			
Branchiostoma lanceolatum (Ceph)	$0.0001\ (d)^{3.332}$	0.88	34

Samples were sieved through a 0.5 mm screen, the biotic residue sorted, and preserved in buffered formalin. The organisms retained by the sieve were counted and classified to the lowest possible taxonomic level for polychaetes, bivalves, and echinoderms. The rest were classified only to major groups. The most important macroinfaunal species of the bay were selected for a quantitative analysis of their life cycles. Depending on the species, length or width of all individuals of those selected species was measured through a binocular microscope equipped with a camera lucida and digitizing tablet (Houston Instrument HIPad) linked to a computer. A selection from representative size categories was measured, and then dried for 48 h at 60°C and weighed. Regressions of length or width vs. dry weight were computed and then used to convert size measurements to biomass (Table 1). For the remaining taxa, biomass was determined as dry weight (24 h at 60°C) except for calcified species, where biomass was derived from the loss of weight after ashing (5 h at 450°C).

In July 1995, a benthic mapping of the entire bay was carried out. Some 37 samples were taken and analysed according to the methodology decribed above. The mapping helped us to check the status of several invertebrate populations in the bay and to make comparisons with previous data.

The monthly catch statistics of the bivalve species fished in these sand deposits and landed in the fishing port of Blanes were analysed.

Results

Sediment characteristics

Coarse to medium-sand sediments characterized station 1 before dredging (mean grain size 575 µm; percentage silt clay of 0.25%; annual mean sediment organic matter of 0.71% dw, range between 0.31 and 1.11; Fig. 2), but the granulometrical parameters had changed completely after dredging. In December 1994, 15 days after the end of sand extraction, the composition was heterogeneous: 40% of the weight was formed by a coarse fraction while the rest consisted of fine to very fine sand. The coarse fraction related to the rough hydrodynamic conditions and strong waves characteristic of the end of autumn, while the fine particles can be attributed to redeposition processes after dredging. Natural sedimentation in the created depression allowed the sediment to recover their normal granulometrical indices in less than one year. However, mean grain size of the deposits did not go up to 0.3 mm until the end of summer 1995 (Fig. 2, inset). The mean total organic content of the sediments was always around 1% and similar to the values obtained before, except during the first months after dredging when values around 2.5% were reached.

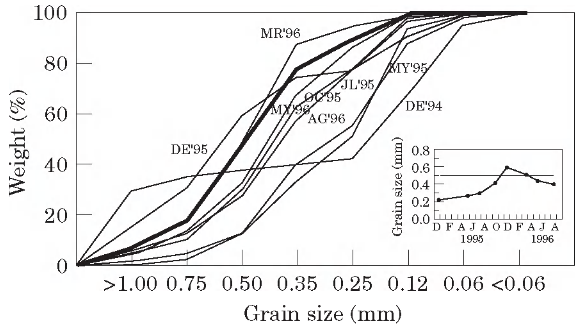

Figure 2. Cumulative granulometric frequency curves of sediments at station 1 through time (thick line: January 1994, before dredging started). Inset: evolution of the mean grain size (horizontal line: January 1994).

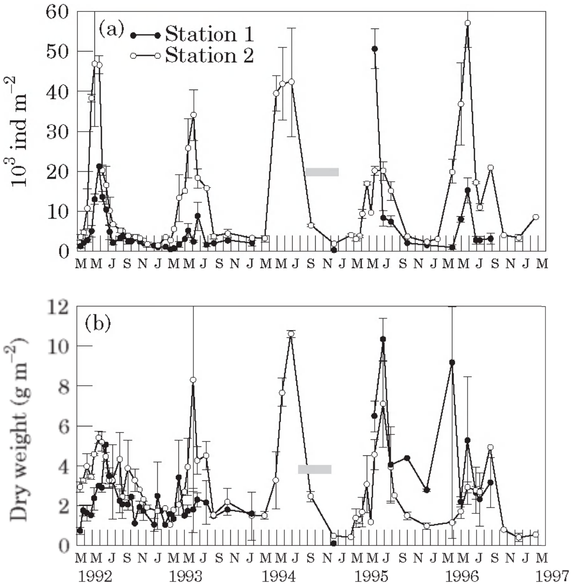

Figure 3. Total abundance (a) and biomass (b) of macroinfauna at stations 1 and 2 (shaded bars: period of dredging operations; vertical bars: standard errors of the mean).

Seasonal dynamics and faunal composition

The general seasonal pattern in total macroinfaunal abundance at the two stations was characterized by a peak during spring, a sharp decrease throughout the summer period, and low values in autumn and winter (Fig. 3). Trends in biomass mirror trends in number of individuals during most years, with peaks in spring following recruitment events of the most important species (Table 2).

Samples obtained at station 1, just after dredging, showed an almost complete defaunation (Fig. 3). Only a few specimens of the polychaete *Capitella capitata* were found, possibly feeding on the organic debris accumulated in the depression created by the suction dredge. During the following year (1995), spring recruitment of several species (*Ditrupa arietina*, *Spisula subtruncata*, *Owenia fusiformis*, and *Echinocardium mediterraneum* being the most important) was very intense, although most of the juveniles did not survive the following summer, as is common for these communities (Fig. 3a). Two species experienced particularly large increases as part of the recolonization process, *Ditrupa arietina* and *Spisula subtruncata*. These two species show annual cycles in these habitats with a near-disappearance of new recruits a few months after settlement. The numbers reached in 1995 at station 1 by these two species were similar to the peaks observed at station 2 during other years, and clearly higher than the ones reached at this site before dredging (see also Sardá *et al.*, 2000). At the end of summer, another species, the lancelet *Branchiostoma lanceolatum*, recruited in large numbers at station 1. The lancelet shows a different seasonal pattern compared with most other species in the bay, recruiting in late summer and early autumn. During 1996, recruitment was back to the level observed prior to dredging and temporal density variations could be considered as normal.

The abundance of species such as *Owenia fusiformis* and *Spio decoratus* (Table 2) did not show a consistent response to dredging activities. The densities reached after dredging were similar to the ones obtained before. However, there were also species (*Glycera* spp., *Protodorvillea kefersteini*, and *Callista chione*) that were frequent before dredging and had not reached the same population levels two years after.

Although dredging might have had some influence on nearby areas, no clear effect could be detected in the dynamics of the macroinfaunal assemblage inhabiting the sediments of station 2, where most species reached similar numbers before and after dredging activities (Table 2). Only two bivalve species (*S. subtruncata* and *L. divaricata*) showed increases after dredging, although the relationship with the anthropogenic disturbance was unclear and might be related to natural interannual variability.

The major contributor to biomass at station 1 before dredging was *Callista chione* (Table 2). Two years after dredging, biomass values were dominated by two echinoderms *Echinocardium mediterraneum* and *Ophiura texturata*, and an unidentified species of sea cucumber. These species recruited in large numbers during 1995, apparently because the disturbed sediments provided a good habitat, and they reached large population sizes during 1996. While for several important species, biomass values one year after dredging were two or three times higher than before, the biomass of *E. mediterraneum* was even an order of magnitude higher. Consequently, biomass of the entire assemblage remained relatively high throughout 1995/1996, even during autumn and winter (Fig. 3b).

After dredging, biomass of the brown venus clam *C. chione*, a commercial valuable species fished by small boats in the bay, was drastically reduced, particularly at the station in the dredged area. From March 1992 to March 1994, prior to dredging, a mean annual abundance of 10 ind m^{-2} with a mean biomass of 0.90 g dw m^{-2} and a mean length of 2.3 cm was observed at station 1. At station 2, the mean annual abundance was 2 ind m^{-2} with a biomass of 0.19 g dw m^{-2}. From March 1995 to March 1996, one year after dredging, the mean annual density at station 1 was 6 ind m^{-2} with a biomass of 0.007 g dw m^{-2} at station 1, while the density at station 2 was 13 ind m^{-2} with a biomass of 0.12 g dw m^{-2}.

Table 2. Mean annual macroinfaunal abundance (individuals m^{-2}), and biomass (g dry weight m^{-2}), during pre-dredging and post-dredging periods (station 1: May 1992–May 1993 and May 1995–May 1996, respectively; station 2: March 1992–March 1994 and March 1995–March 1997, respectively).

	Abundance		Biomass	
Station 1	1992–1993	1995–1996	1992–1993	1995–1996
Polychaetes				
Ditrupa arietina	724	2842	0.193	0.268
Owenia fusiformis	392	480	0.120	0.598
Glycera spp.	303	58	0.352	0.099
Protodorvillea kefersteini	188	18	0.046	0.002
Spio decoratus	131	200	0.015	0.015
Capitella capitata	52	110	0.002	0.003
Echinoderms				
Echinocardium mediterraneum	104	70	0.152	2.724
Ophiura texturata	5	14	0.113	0.236
Bivalves				
Spisula subtruncata	706	1972	0.092	0.323
Callista chione	14	6	1.182	0.007
Cephalochordates				
Branchiostoma lanceolatum	128	1012	0.025	0.179
Total macroinfauna	4713	7729	3.344	5.284
Station 2	1992–1994	1995–1997	1992–1994	1995–1997
Polychaetes				
Owenia fusiformis	3501	4484	0.638	0.882
Paradoneis armata	401	178	0.057	0.019
Ditrupa arietina	10	85	0.005	0.119
Mediomastus fragilis	277	133	0.021	0.005
Spio decoratus	129	126	0.013	0.008
Glycera rouxii	15	27	0.025	0.013
Echinoderms				
Echinocardium mediterraneum	215	3	0.130	0.003
Bivalves				
Spisula subtruncata	949	2566	0.070	0.123
Lucinella divaricata	462	1680	0.023	0.054
Callista chione	2	13	0.190	0.120
Total macroinfauna	97	12 167	2.826	1.929

Bivalve fisheries

From 1990 to 1994, an annual mean bivalve catch of 26 t (wet weight) was landed in Blanes harbour by the artisanal fleet. *C. chione* accounted for 40% of the catch while the tellinids *Donax trunculus* and *D. variegatus* made up another 40%, *Acanthocardia aculeata* 9%, and the rest consisted of *Venerupis decussata* and *Chamelea gallina*. The catch showed a marked seasonality (Fig. 4). Monthly catches were higher during spring and summer, and lower during the rest of the year. These trends are related to the more favourable sea conditions during spring and summer, which are required by the fleet before they can leave harbour.

The total catch declined markedly and consistently after dredging (Fig. 4). From 1995 to 1997, on average only 11 t of bivalves were landed per year. Although the reduction affected all six species, the declines have been more pronounced for *A. aculeata* (90% reduction), *C. chione* (65%) and *C. gallina* (100%), and less so for *D. trunculus* and *D. variegatus* (40%) and *V. decussata* (35%). These latter three species were taken in the western part of the Delta front, in fine-sand sediments that were less affected by the dredging operation due to its unsuitability (type and size) for beach restoration.

Discussion

Growing concern about human influence on marine ecosystems conflicts with our inability to separate man-made impacts from natural change (Duarte *et al.*, 1992). The shallow soft-bottom sediments on the Catalan coast are continuously stressed by man-made disturbances

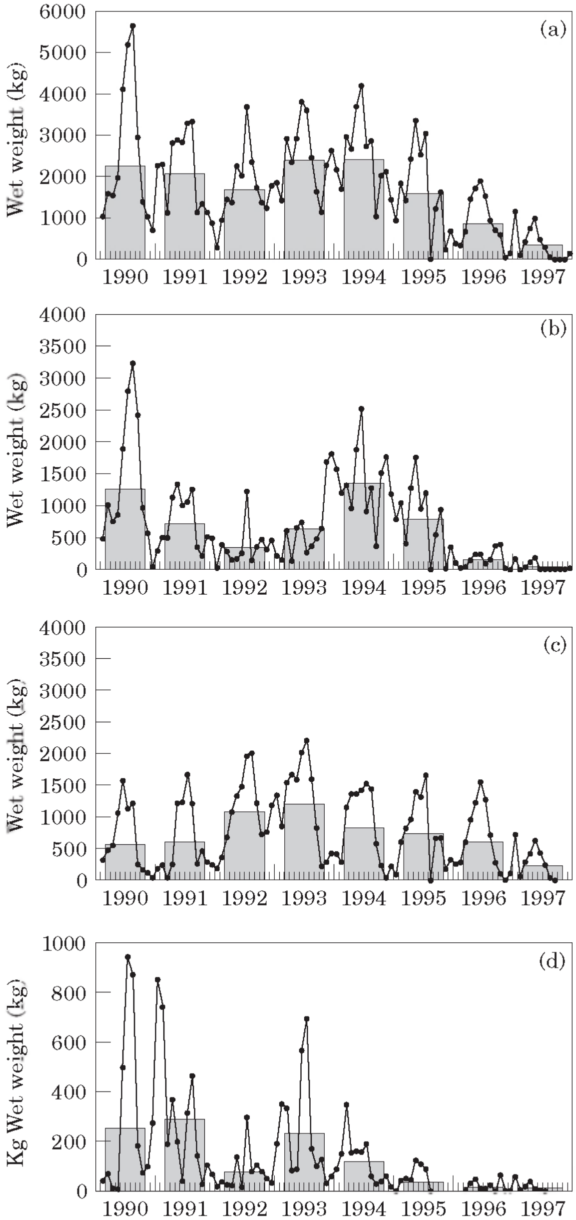

Figure 4. Temporal variation in monthly (dots) and average monthly (shaded bars) catch (kg wet weight including shells) of bivalves by the artisanal fleet fishing from Blanes, 1990–1997: (a) total; (b) *Callista chione*; (c) *Donax variegatus* and *D. trunculus*; (d) *Acanthocardia aculeata*.

(offshore construction, dredging activities, recreation, trawl fisheries; Sardá and Fluviá, 1999) and the associated communities are permanently affected. The monitoring programme of the Bay of Blanes (Duarte, 1996) serves as an adequate baseline from which to discern the effects of dredging operations on this type of community.

Benthic recolonization in the disturbed sediments was fast and followed structural evolution patterns observed in other areas (Hily, 1983). By the end of the dredging period, large quantities of sediment were removed and macrofauna had almost disappeared. After a short period of heterogeneous sediment composition and presence of organic debris, the depressions were gradually replenished by new sand deposits, and mean grain size composition reached pre-dredging values in less than one year. The presence of fine-sand deposits during the next spring favoured settlement of several pioneer species such as *D. arietina* and *S. subtruncata*, which attained high numbers in a few months. In addition, other invertebrate species such as *O. fusiformis*, *E. mediterraneum*, *O. texturata*, and *B. lanceolatum* showed high recruitment values during the first year. Pinedo *et al.* (2000) proved experimentally that the small fraction of the sediment plays an important role in structuring an *O. fusiformis* population and similar processes might apply for other species. Altogether, these species were responsible for the significant increase in biomass observed after dredging stopped.

Despite high abundances and large biomasses, there were no changes in the seasonal trends of these shallow soft-bottom assemblages after dredging. In contrast to reports for other areas (Arntz and Rumohr, 1982; Bonsdorff, 1983; Hily, 1983) where after defaunation total biomass increased gradually through the following years until reaching normal values, dredging of the Tordera deposits favoured rapid increases in biomass directly after the activities stopped. Based on two years of data, the trend was decreasing instead of increasing. The initial increase in biomass was mainly due to rapid growth of echinoderm species, while the decrease thereafter was caused by adult mortality and by the absence of successful recruitment during the second year.

The number of species in the dredged zone also recovered rapidly and most populations reached a large size after two years. However, other species such as *C. chione* and the carnivorous polychaetes *Protodorvillea kefersteini* and *Glycera* spp. were still clearly reduced, suggesting that more than two years would be necessary to return to original population sizes and compositions. Growth of *C. chione* is slow: it takes four years to reach 4 cm in the Mediterranean and the maximum length of 8–8.5 cm is reached when 11–14 years old (Strada and Zocco, 1985). Individuals of *C. chione* were still found at station 1 in 1996–1997 but they were very small. Based on the growth estimates above, it would take at least three years to find capture-size individuals (according to Catalan law, only individuals >2.9 cm may be landed).

The exploitation of offshore deposits to replenish eroded beaches is a normal practice in Catalonia, where thousands of visitors are annually attracted to the beaches. The feasibility of these operations depends on a nearby supply of suitable sand for extraction and on the analysis of potential risks for vital areas (special attention is given to *Posidonia oceanica* meadows). Innovative nourishment techniques should minimize siltation and should not compromise beach profiles by not using the sand reserves of the beach area. The delta front of the Tordera River was selected based on its vicinity to eroded beaches, the type and size of the sand deposits, the high sediment deposition rate, and the lack of *Posidonia oceanica* spots in the area. The data allow us to consider another important topic normally not considered, i.e., the risks of losing important benthic resources and its consequences for the controls of benthic marine food webs (Foreman *et al.*, 1995), including human consumption. The fast recovery observed after dredging was apparently dependent on the sediment conditions during the following spring recruitment. Thus it would seem that the time chosen (3rd and 4th quarter) is appropriate for maximizing potential recovery.

Bivalve fisheries on this sandbank began more than 20 years ago, and a small artisanal fleet has been maintained until recently. However, the official catch data showed a clear trend of decreasing yield since dredging stopped. The populations of slow-growing species, such as *C. chione* and *A. aculeata* will require several years to reach their previous numbers. Meanwhile, continued fishing on these small populations is dangerous because this may deplete the last adult organisms. In the past, the artisanal fleet developed a managerial strategy by which no fishing was allowed at different sites on the bank to maintain a shellfish stock for the future (Blanes Fishermen Association, pers. comm.). After dredging, these practices were forgotten and two of the four boats went out of business in 1996, while only one boat was in business by 1997. No compensatory measures have been introduced when dredging activities were carried out and some fishermen that could claim for subsistence interests have no formal property rights in these invertebrates. The bivalve fisheries had probably another indirect effect on the benthic community by limiting the size attained by the invertebrates inhabiting these grounds. Because the remaining boats exploit mainly the western part of the bank, the fishing effort around station 1 appears to have diminished. This may have favoured the local presence of the larger individuals.

Anthropogenic disturbances such as artisanal bivalve fisheries and dredging are important controls in regulating the dynamics of soft-bottom assemblages of the western Mediterranean, and biomass in particular might be highly dependent on these activities. The absence of long-lived organisms and the selective pressure on larger invertebrates make that these assemblages are structured mainly by pioneer annual species, which explains the great predictability of their seasonal dynamics.

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