Changes in benthic community structure due to clam dredging on the Algarve coast and the importance of seasonal analysis

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Patterns in community structure of meiofauna and macrofauna in relation to Portuguese clam dredging were compared during a 2-y-period off Lagos and Vilamoura, south Portugal. SCUBA divers randomly sampled corer and quadrat samples before and immediately after simulating commercial dredge fishery. Univariate measures (abundance, number of taxa, evenness, diversity and biomass) and multivariate analyses (Cluster, MDS and SIMPER) revealed changes in the meio- and macro-benthic community structure caused by dredge disturbance (short-term effects), with a general decrease in all measures. Macrofauna were found to be more sensitive to dredge disturbance, and aggressive predatory behaviour was observed after disturbance in the continuously dredged area. Nevertheless, higher significant natural changes were found between seasonal periods, indicating that dredging may only cause a small-scale and short-term impact.

INTRODUCTION

Commercial fishing can affect benthic communities by directly removing and/or injuring surface-living organisms in the path of the equipment, or by digging into the sediment and thus affecting both infauna and the epibenthos (Bergman & Hup, 1992; Tuck et al., 1998). The environmental effects of shellfish dredging have thus received particular recent attention worldwide (see Caddy, 1968, 1973; Meyer et al., 1981; Hall et al., 1990; Kaiser & Spencer, 1996; Jennings et al., 2001).

In Portugal, bivalve dredging has played important economic and social roles since 1969. Today, the industry targets the species *Spisula solida*, *Donax trunculus*, *Venus striatula*, *Pharus legumen* and *Ensis siliqua* (Gaspar, 1996). Bivalves are caught with a dredge that can penetrate into the sediment up to 50 cm, depending on the target species and sediment type. However, only recently has concern developed about the possible impact of dredging on the fauna of Portuguese waters, as shown by studies of damage to *E. siliqua* (Gaspar et al., 1994, 1998, 2001), predatory aggregation (Chícharo et al., 2003) and diversity along dredge track sections (Chícharo et al., 2002a).

In general, dredges are designed to dig into the surface of the sediment and can cause extensive mortality to the benthic organisms, particularly in areas with an established sessile epifauna (Holme, 1983; Robinson & Rowell, 1990; Kaiser & Spencer, 1994). The dredge fishery's impact upon benthic communities is responsible for changes in biodiversity, taxonomic composition, feeding habits and community structure (Currie & Parry, 1996, 1999; Jennings et al., 2001). These changes in the community structure caused by fishing disturbance can be detected on a short-term scale (de Groot, 1984; Currie &

Parry, 1996; Kaiser & Spencer, 1996; Pranovi & Giovanardi, 2000). Such studies can provide reliable results; however, long-term effects are more difficult to evaluate and are consequently scarce in the literature (Witbaard & Klein, 1994; Tuck et al., 1998).

The analysis of seasonal changes in benthic assemblages is also of major importance in ecological studies. Seasonal variations among several marine coastal benthic communities of the north-east Atlantic have been studied in the North Sea (Buhl-Jensen & Fossa, 1991; Hamerlynck & Mees, 1991), the Baltic Sea (Ólafsson & Elmgren, 1997), the Celtic Sea (Bottrell & Robins, 1984), the Bay of Biscay (Sorbe, 1999) and the west coast of Portugal (Ría de Aveiro; see Cunha et al., 1999). However, there has been no analysis of the seasonal variations of the meio- and macro-fauna benthic communities of the south Portuguese soft-bottom coastal waters.

The results presented here concern sampling in two areas of the Algarve coast during a 2-y-period, to investigate the short-term changes in the meiofauna and macrofauna benthic communities structure caused by clam dredging, and to compare them within seasonal variations. The results are discussed in relation to overall fishing impact for the areas, and highlight the importance of seasonal fluctuations for an accurate assessment of short-term changes.

MATERIALS AND METHODS

Sampling design

The research vessel 'Donax' undertook dredging at a site 7–9 m deep (plummet data) off Falésia Beach, Vilamoura, and off Lagos Bay, both in the Algarve region of South Portugal (Figure 1) in April and October 1999, and in
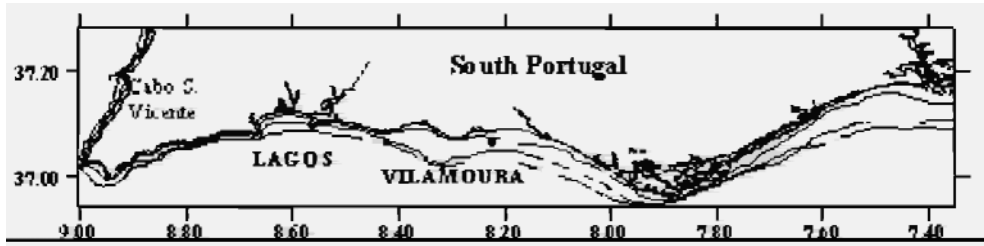
Figure 1. The South Portugal (Algarve) coast, showing location of the studied areas: Lagos and Vilamoura (according to Chícharo et al., 2002b).

Table 1. *Significance levels from two-way ANOVA tests for differences in various univariate measures of community structure (see text) between: (1) before/after dredging; (2) seasons; and (3) interaction between both, for meiofauna and macrofauna at Lagos and Vilamoura.*

| Univariate measure | Meiofauna | | | | | | Macrofauna | | | | | |
| | Lagos | | | Vilamoura | | | Lagos | | | Vilamoura | | |
	1	2	1×2	1	2	1×2	1	2	1×2	1	2	1×2
A ($\checkmark\checkmark$)	<0.01	<0.01	<0.01	0.07	<0.01	0.05	<0.01	<0.01	<0.01	0.43	<0.01	0.09
T ($\checkmark\checkmark$)	<0.01	0.04	<0.01	<0.01	0.12	0.92	<0.01	<0.01	<0.01	0.87	<0.01	0.02
$\mathcal{J}$	0.06	<0.01	0.46	0.12	<0.01	0.13	0.04	<0.01	0.16	0.17	0.6	0.31
H'	0.19	<0.01	0.76	<0.01	0.04	0.08	<0.01	<0.01	0.12	0.56	<0.01	<0.01
B ($\checkmark\checkmark$)	<0.01	<0.01	0.66	0.5	<0.01	0.24	0.37	<0.01	0.34	0.66	<0.01	0.05

Table 2. *Mean and standard deviations of the meiofauna abundance (m^2) before and after dredging, at Lagos and Vilamoura, using data from all seasonal periods. n. id., non identified. Blanks represent zeros.*

| Meiofauna taxa | Lagos | | Vilamoura | |
	Before	After	Before	After
Phylum NEMATODA	293730 ±263584	127677 ±99623	122450 ±125925	84000 ±86434
Class TURBELLARIA	29230 ±175552	435 ±861	450 ±605	219 ±608
Class OLIGOCHAETA	11932 ±34576	2565 ±6232	300 ±571	250 ±718
Order COPEPODA	9378 ±13223	5516 ±12117	18600 ±22993	12031 ±25555
Class POLYCHAETA	6554 ±6194	3694 ±3405	2400 ±6012	844 ±1568
Order ISOPODA	1770 ±8921	65 ±248	300 ±571	94 ±390
Phylum NEMERTINEA	1203 ±3351	1645 ±8667	1400 ±2741	969 ±2845
Class BIVALVIA	1122 ±3515	1113 ±3398	400 ±754	1594 ±3826
Order AMPHIPODA	797 ±3701	210 ±547	100 ±308	31 ±177
Order OSTRACODA	608 ±1004	242 ±645	550 ±1395	406 ±798
Order TANAIDACEA	446 ±846	484 ±1036		
Phylum TARDIGRADA	243 ±857	32 ±254		
Phylum CNIDARIA	189 ±734	16 ±127		31 ±177
Class GASTROPODA	135 ±448			31 ±177
Ordern CUMACEA	68 ±302	48 ±216	50 ±224	63 ±246
Class HALACAROIDEA	68 ±253		950 ±1356	469 ±915
Order CLADOCERA		16 ±127		
Phylum SIPUNCULO				250 ±1107
n. id. Taxa	176 ±866	97 ±534	100 ±308	31 ±177

July and October 2000. On each occasion, a commercial Portuguese clam dredge (Figure 2) was used. The dredge was towed for 1 min at a mean speed of 2 knots; this fishing speed is similar to that used by commercial dredge fleets. Our survey was done with the type of dredge used by commercial fishers for the clam *Spisula solida*. The dredge is a large, heavy iron structure, with a 25-mm mesh net bag and a toothed lower bar at the mouth. The gear's mouth can be up to 100 cm wide, with teeth up to 10 cm in length, which act as a rake when the dredge is dragged over the sea bottom (Gaspar, 1996).

Six replicate quadrats ($0.0625 \text{ m}^2 \times 0.15$ m depth) for macrofauna and four replicate corers ($0.001 \text{ m}^2 \times 0.15$ m depth) for meiofauna were randomly sampled by SCUBA divers from the dredge track immediately after dredging. The control samples were collected from the study area
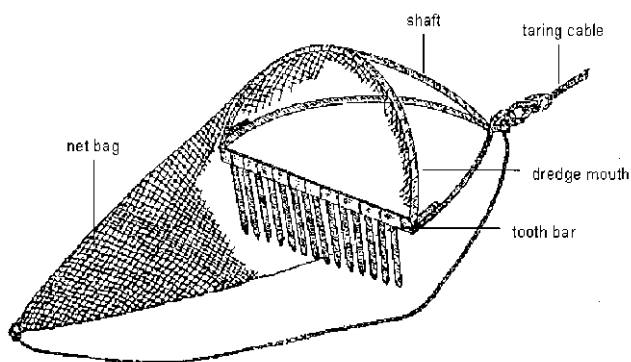
Figure 2. Representative view of a Portuguese clam dredge (according to Monteiro, 1985). Tooth bar, 100 cm; tooth size for *Spisula solida*, 10 cm; space between tooth, 1.5 cm; net bag, 25-mm mesh size.

before dredging, using the same method and number of replicates. This procedure was performed in triplicate on each occasion and location. Macrofauna were sieved *in situ* using 1-mm mesh bags.

Laboratory procedure

All the residues were preserved in 70% ethanol. Meiofauna were sieved using a 500-μm (upper limit) and 150-μm (lower limit) mesh sieve. Identification of all organisms in a community to species level is a major time and cost constraint (Warwick, 1993; Clarke & Warwick, 1994; Somerfield & Clarke, 1995). Moreover, many studies on meio- and macro-benthic disturbance have shown that very little information is lost by working at a taxonomic level higher than species (e.g. family or even phylum; see Heip et al., 1988; Herman & Heip, 1988; Warwick, 1988;
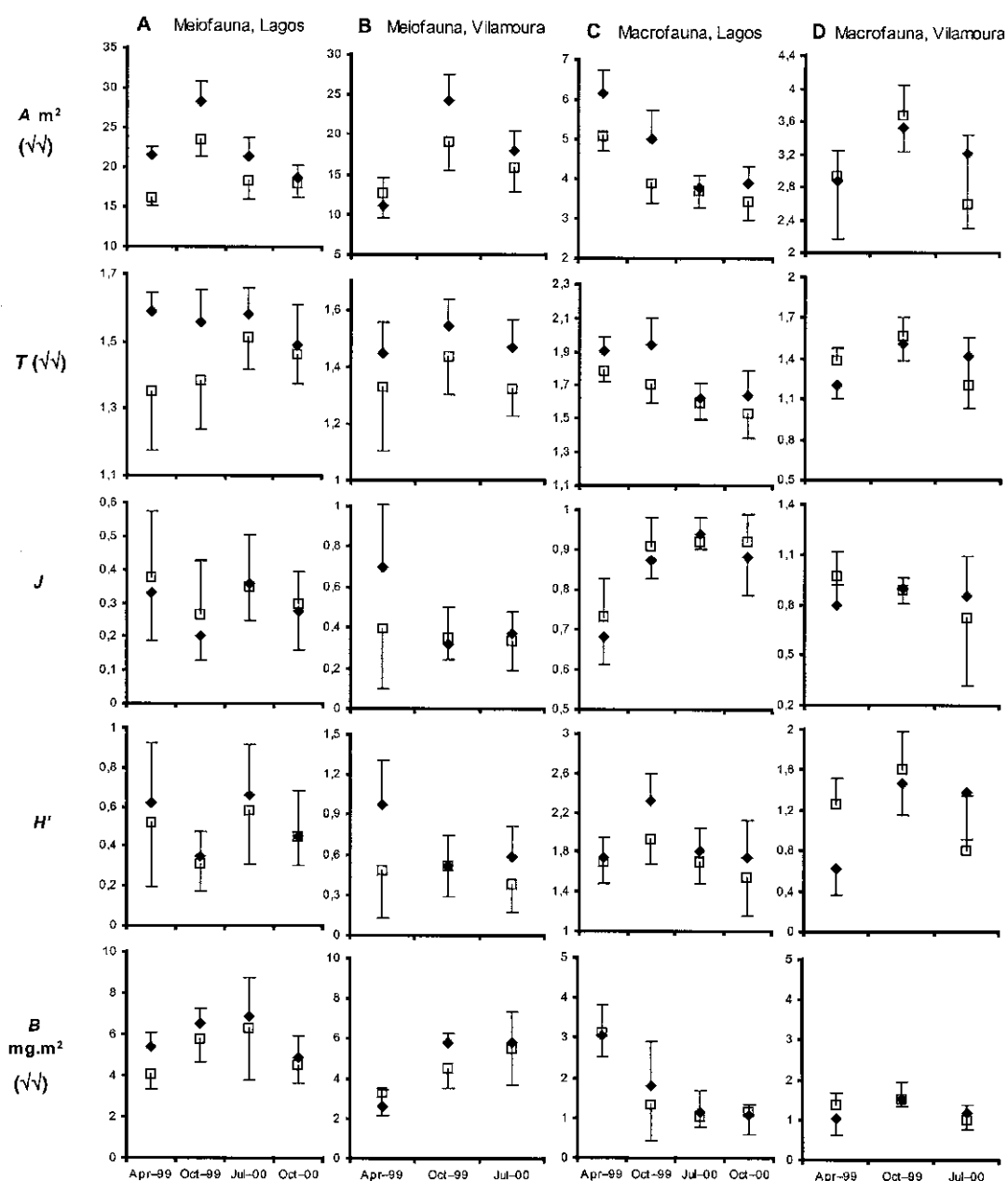

Figure 3. Means and standard deviations of univariate measures: abundance (A), number of taxa (T), Pielou's J, Shannon–Wiener diversity (H') and biomass (B) before ($\blacklozenge$) and after ($\square$) dredging for: (A) meiofauna from Lagos station; (B) meiofauna from Vilamoura station; (C) macrofauna from Lagos station; (D) macrofauna from Vilamoura station.

Table 3. *Means and standard deviations of the macrofauna abundance (m^2) before and after dredging, at Lagos and Vilamoura, using data from all seasonal periods. n. id., non identified. Blanks represent zeros.*

Macrofauna taxa		Lagos		Vilamoura	
		Before	After	Before	After
Phylum NEMERTINEA	n. id. Nemertinea	16.0 ±31.8	1.3 ±4.4		0.4 ±2.4
Phylum PRIAPULA	n. id. Priapula	0.2 ±1.7			
Phylum SIPUNCULO	n. id. Sipunculo	10.9 ±20.1	2.8 ±7.6		
Phylum ECHIURA	n. id. Echiura	0.2 ±1.7			
Class POLYCHAETA	Amphictenidae	3.8 ±10.9	6.4 ±14.9		
	Aphroditidae	1.3 ±6.6	1.7 ±6.7		0.4 ±2.4
	Arenicolidae		0.2 ±1.8	1.5 ±4.7	0.4 ±2.4
	Capitellidae	10.0 ±19.6	0.9 ±3.6		0.4 ±2.4
	Chaetopteridae	0.2 ±1.7			
	Chlorhaemidae	0.6 ±3.0			
	Cirratulidae	1.7 ±6.5		3.9 ±16.0	4.6 ±12.6
	Eunicidae	6.6 ±14.5	0.6 ±3.2		0.4 ±2.4
	Glyceridae	1.1 ±4.8		2.4 ±5.8	2.8 ±9.2
	Hesionidae	0.2 ±1.7	0.2 ±1.8		
	Magelonidae		0.2 ±1.8		
	Maldanidae	2.8 ±7.5	3.0 ±7.3		
	Nephtydidae	8.5 ±14.9	2.6 ±5.9	10.2 ±14.3	4.3 ±8.6
	Nereidae	1.9 ±6.3	2.1 ±6.1	2.9 ±8.4	5.0 ±11.7
	Opheliidae	0.2 ±1.7		0.5 ±2.8	0.7 ±4.8
	Orbiniidae	1.1 ±4.8	2.1 ±8.9	0.5 ±2.8	0.7 ±3.3
	Oweniidae	0.2 ±1.7	0.2 ±1.8	0.5 ±2.8	
	Phyllodocidae	1.7 ±7.0	0.6 ±3.2		0.7 ±3.3
	Sabellaridae	0.2 ±1.7			
	Sabellidae	1.7 ±5.5	0.2 ±1.8		
	Serpulidae		0.4 ±2.6		
	Spionidae	1.9 ±5.7	1.7 ±6.7		1.8 ±6.1
	Syllidae	0.2 ±1.7			
	Terebellidae	1.1 ±5.9	2.8 ±8.5		
	n. id. Polychaeta	2.4 ±9.7	1.5 ±5.4		0.7 ±3.3
Class BIVALVIA	*Abra alba*	5.6 ±32.4			
	A. ovata	2.6 ±13.9			
	Acanthocardia aculeata	0.2 ±1.7			
	A. echinata	0.2 ±1.7			
	A. tuberculata	1.3 ±5.1	2.8 ±8.1		
	Anomia ephipium				0.4 ±2.4
	Callista chione	0.2 ±1.7	0.2 ±1.8		
	Chamelea gallina	5.3 ±14.3	3.6 ±10.4	1.0 ±3.9	1.8 ±6.1
	Corbula gibba	0.6 ±3.0	0.2 ±1.8	1.0 ±3.9	0.4 ±2.4
	Digitaria digitaria		0.4 ±2.6		
	Divaricela divaricata	9.6 ±16.2	8.5 ±12.4		0.4 ±2.4
	Donax trunculus	0.8 ±4.2			
	D. variegatus	6.6 ±34.8		1.0 ±3.9	0.7 ±3.3
	D. venustus	0.9 ±3.8	0.6 ±3.2		
	D. vittatus	1.7 ±11.0			0.4 ±2.4
	Dosinea exoleta	0.8 ±5.5	0.9 ±3.6	1.5 ±4.7	
	Ensis siliqua				0.4 ±2.4
	Ervilia nitens	0.2 ±1.7			
	Gari depressa			0.5 ±2.8	
	G. fervensis	0.2 ±1.7			
	Loripes lucinalis	0.4 ±2.4	0.2 ±1.8		0.4 ±2.4
	Lutraria anguistor	1.9 ±8.3	2.8 ±10.3		
	Mactra corallina	0.4 ±2.4			
	M. glauca	0.2 ±1.7			0.4 ±2.4
	Modilous adraticus			0.5 ±2.8	0.4 ±2.4
	M. barbatus			0.5 ±2.8	
	Myrtea spinifera	0.4 ±3.5	0.2 ±1.8		
	Mysella bidentata	58.9 ±159.0	48.4 ±128.0		
	Mysia undata	0.2 ±1.7			
	Pandora inequivalvis	0.2 ±1.7			
	Pharus legumen	0.4 ±2.4	0.4 ±2.6		

Table 3. *Continued.*

|					
	Scrobicularia plana	4.3 ±21.0	0.4 ±2.6		0.4 ±2.4
	Spisula elliptica	1.5 ±7.7	1.5 ±7.0	0.5 ±2.8	
	S. solida	2.8 ±11.4	0.4 ±2.6	27.2 ±72.1	8.9 ±16.6
	Spisula subtruncata	0.6 ±3.9	0.6 ±3.2		
	Tellina incarnata		0.4 ±2.6	0.5 ±2.8	3.9 ±12.4
	T. tenuis	1.1 ±4.8	0.4 ±2.6	3.9 ±9.8	1.4 ±4.6
	Thracia papyracea	1.7 ±5.5	3.2 ±8.7		
Class GASTROPODA	*Bela oceanica*	0.4 ±3.5			
	B. ornata	0.2 ±1.7			
	Calyptraea chinensis			4.8 ±11.7	6.8 ±18.5
	Cylichna cylindracea	0.4 ±2.4			
	Eulima glabra	0.6 ±3.0	1.1 ±4.8		
	Euspira catena				0.4 ±2.4
	E. guillemini	0.2 ±1.7	0.2 ±1.8		
	E. macilenta		0.4 ±2.6		
	Gibbula magus				0.4 ±2.4
	Gibberula cf. *miliaria*	3.2 ±9.8	3.4 ±9.6		
	Leiostraca sebulata	0.2 ±1.7			
	Mesalia brevialis	0.8 ±3.4	0.4 ±2.6		
	Philine aperta	0.2 ±1.7	0.2 ±1.8		
	Turritella communis	10.0 ±16.6	6.2 ±16.4		
Class SCAPHOPODA	*Fustiaria rubescens*	0.6 ±3.9	0.9 ±4.5		
Class OSTRACODA	n. id. Ostracoda	0.4 ±2.4	0.2 ±1.8		
Class COPEPODA	n. id. Copepoda	0.4 ±2.4			
Order CUMACEA	*Iphinoe trispinosa*	0.8 ±4.2		1.0 ±3.9	0.7 ±3.3
Order TANAIDACEA	*Apseudes latreillii*	7.0 ±14.1	0.4 ±2.6		
	Tanais dulongii				0.4 ±2.4
Order MYSIDACEA	*Gastrosaccus sanctus*	1.1 ±4.1			
	Gastrosaccus sp.	0.4 ±2.4	0.2 ±1.8		
	Schistomysis spiritus			1.0 ±3.9	
Order ISOPODA	*Cyathura carinata*	0.8 ±4.2	0.4 ±2.6		
	Cirolana cranchii		0.4 ±2.6	1.0 ±3.9	1.1 ±4.0
	Eurydice spinigera	2.4 ±8.0	0.4 ±2.6		1.8 ±7.8
Order AMPHIPODA	*Ampelisca brevicornis*	61.0 ±95.1	20.7 ±47.4	0.5 ±2.8	
	Atylus vedlomensis	0.6 ±3.0	0.6 ±3.2		0.7 ±3.3
	Dexamine spinosa	10.7 ±26.6	2.6 ±6.5	2.4 ±7.1	4.3 ±14.2
	Hippomedon denticulatus	7.7 ±15.7	1.3 ±5.1	0.5 ±2.8	1.1 ±4.0
	Monoculodes carinatus	0.4 ±2.4	0.2 ±1.8		0.7 ±3.3
	Photis cf. *longipes*	0.2 ±1.7	1.1 ±5.5		0.4 ±2.4
	Phtisica marina		1.7 ±14.8		
	Pontocrates arenarius	0.9 ±5.7	0.2 ±1.8	1.0 ±5.6	
	Siphonoecetes striatus	20.5 ±28.9	17.3 ±31.5	1.5 ±6.1	0.7 ±3.3
	Urothoe poseidonis	37.8 ±41.4	18.8 ±29.6	8.7 ±23.4	3.6 ±15.0
Order DECAPODA	*Atelecyclus undecimdentatus*		0.2 ±1.8		
	Philocheras trispinosus	0.4 ±2.4	0.2 ±1.8		
	Diogenes pugilator	32.4 ±47.3	17.5 ±25.9	0.5 ±2.8	0.7 ±4.8
	Hippolyte varians		0.2 ±1.8		
	Liocarcinus holsatus	0.8 ±6.9			
	L. marmoreus		0.6 ±5.5		
	L. pusillus	0.2 ±1.7	0.9 ±3.6	0.5 ±2.8	
	L. vernalis	0.2 ±1.7			
	Parthenope massena				0.4 ±2.4
	Pirimela denticulata	0.2 ±1.7			0.4 ±2.4
	Processa parva	2.8 ±7.5	1.7 ±8.1	2.9 ±7.4	1.8 ±5.1
	Thia scutellata	0.4 ±2.4	0.4 ±2.6		
Class ASTEROIDEA	*Astropecten irregularis*		0.2 ±1.8		0.4 ±2.4
Class OPHIUROIDEA	*Amphipholis squamata*	0.2 ±1.7			
	Amphiura mediterranea	94.5 ±194.7	21.8 ±42.3	24.7 ±34.0	14.6 ±23.3
	Ophiura texturata	3.4 ±12.4	0.9 ±4.5	10.7 ±18.6	26.7 ±40.5
Class ECHINOIDEA	*Echinocardium cordatum*	6.0 ±9.9	4.3 ±9.2	3.9 ±8.0	5.3 ±7.6
	Echinocianus pusilus	0.2 ±1.7			
	Psamoechinus miliaris				0.4 ±2.4
Phylum HEMICHORDATA	*Branchiostoma lanceolatum*	13.2 ±41.5	1.7 ±6.7	1.5 ±4.7	1.1 ±4.0
InfraClass TELEOSTEI	Teleostei		0.2 ±1.8		
Others	n. id. Taxa	1.5 ±7.2	1.7 ±6.2		
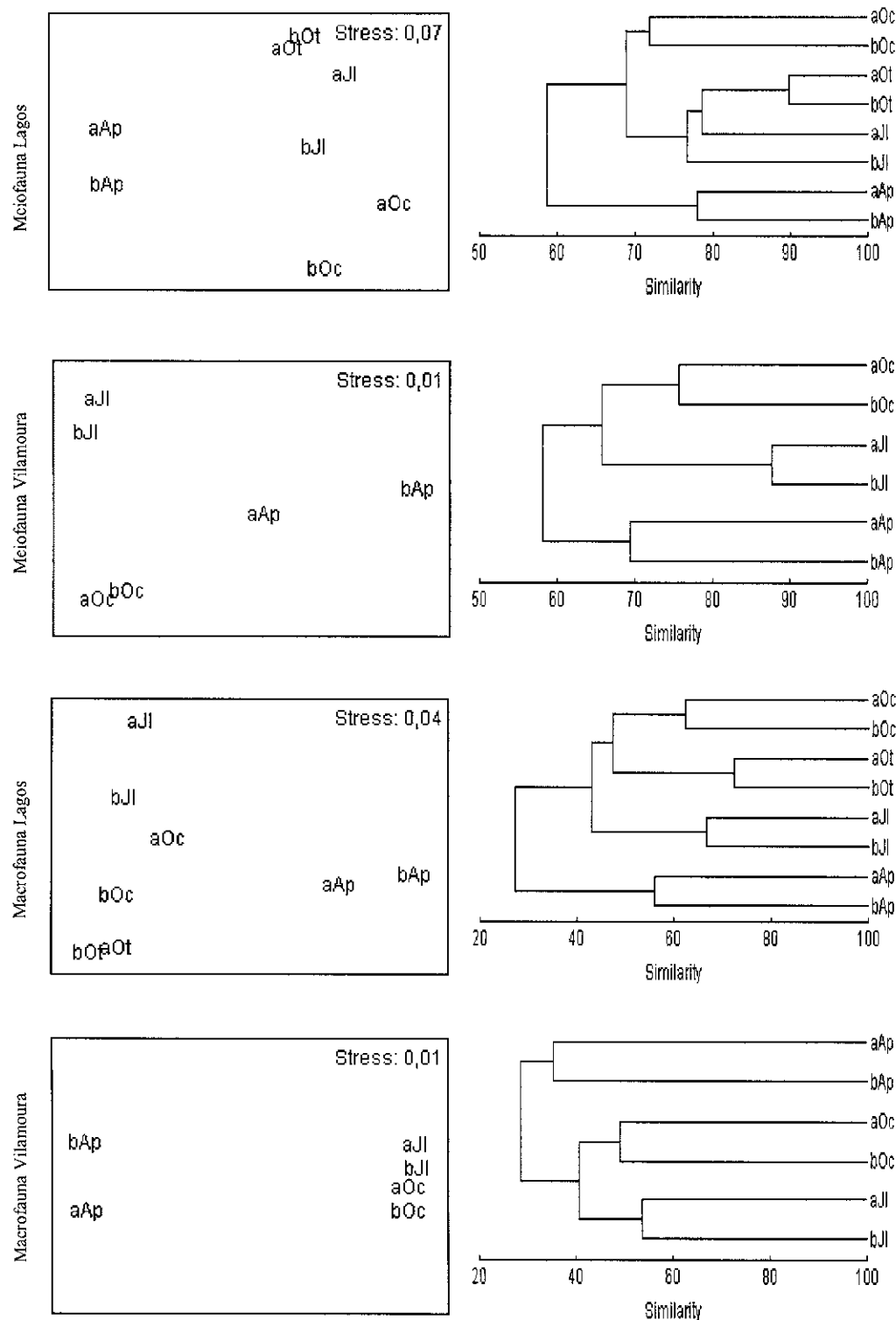
Figure 4. Multidimensional scaling (left) and cluster (right) ordinations for meiofauna and macrofauna abundances from Lagos and Vilamoura, before (b) and after (a) dredging on different seasons (Ap, April 1999; Oc, October 1999; Jl, July 2000; Ot, October 2000).

Warwick et al., 1990). Thus, we decided to sort meiofauna by phylum or order, and to sort macrofauna to the lowest possible taxonomic level with the exception of a few groups.

Ash-free dry weight was calculated for macrofauna biomass determinations. These animals were dried at 60°C until constant weight (at least 48 h) and then burned at 450°C for three hours in a muffle-furnace. Meiofaunal biomass was calculated following Banse (1982), Knox (1986) and Sprung (1994).

Data analysis

Univariate measures of community structure. Univariate measures included: total abundance (A), number of taxa (T), evenness (Pielou's J), Shannon–Wiener diversity indices, which were calculated using base-e logarithms (H'), and biomass (B). A and B were converted to square metres. A, T and B were then converted to approximate normality using a double square root transformation ($\sqrt{\sqrt{}}$), and the

Table 4. *R and significance levels (*P*) from two-way crossed ANOSIM tests for meiofauna and macrofauna community structure between (1) before/after dredging and (2) seasons, at Lagos and Vilamoura.*

Taxa	Area	Effect	R	*P*-level
Meiofauna	Lagos	1	0.138	<0.01
		2	0.651	<0.01
	Vilamoura	1	0.103	0.06
		2	0.483	<0.01
Macrofauna	Lagos	1	0.249	<0.01
		2	0.715	<0.01
	Vilamoura	1	0.218	<0.01
		2	0.521	<0.01

significance of differences between before/after dredging and seasons were tested using two-way ANOVA (*F*-test). This analysis was accomplished for meiofauna and macrofauna in both areas, totalling 20 two-way ANOVA tests. The ANOVA assumptions, namely the normal distribution and the homogeneity of variances, were tested using Chi-square and Levene's tests, respectively. All tests were performed using the STATISTICA 5 program. The mean and standard deviation of species abundance between before and after dredging were also determined for meiofauna and macrofauna in both areas.

Multivariate analyses of community structure. Non-parametric multivariate techniques were used, as discussed by Clarke (1993). Lower triangular similarity matrices were constructed using a range of data transformations and the

Table 5. *Results of the SIMPER analysis applied between before and after dredging on fourth-root transformed meiofauna and macrofauna, at Lagos and Vilamoura, using data from all seasonal periods. The table shows the contribution (contrib.) and cumulative (cum.) per cent of the species that most contribute to the Bray–Curtis dissimilarities. The cut off was 75% for meiofauna and 60% for macrofauna.*

Meiofauna						
Lagos average dissimilarity=37.58				Vilamoura average dissimilarity=45.99		
Taxa	Contrib.%	Cum.%		Taxa	Contrib.%	Cum.%
Class OLIGOCHAETA	13.57	13.57		Order COPEPODA	17.32	17.32
Phylum NEMATODA	13.30	26.88		Phylum NEMATODA	15.25	35.58
Order COPEPODA	11.89	38.77		Class POLYCHAETA	10.34	42.91
Class POLYCHAETA	8.76	47.53		Phylum NEMERTINEA	8.84	51.76
Class BIVALVIA	7.96	55.50		Class HALACAROIDEA	8.68	60.44
Phylum NEMERTINEA	7.31	62.81		Class BIVALVIA	7.63	68.06
Order OSTRACODA	6.91	69.72		Class TURBELLERIA	7.11	75.17
Order TANAIDACEA	6.88	76.61				

Macrofauna						
Lagos average dissimilarity=77.00				Vilamoura average dissimilarity=80.59		
Taxa	Contrib.%	Cum.%		Taxa	Contrib.%	Cum.%
Ampelisca brevicornis	5.22	5.22		*Amphiura mediterranea*	9.42	9.42
Urothoe poseidonis	5.09	10.31		*Ophiura texturata*	9.22	18.64
Amphiura mediterranea	4.93	15.24		*Spisula solida*	9.19	27.83
Diogenes pugilator	4.80	20.04		Nephtydidae	6.88	34.71
Siphonoecetes striatus	4.69	24.73		*Echinocardium cordatum*	5.08	39.79
Mysella bidentata	4.24	28.97		*Calyptraea chinensis*	4.47	44.26
Divaricela divaricata	3.70	32.67		Glyceridae	3.60	47.86
Turritella communis	3.35	36.02		Nereidae	3.58	51.44
Echinocardium cordatum	2.90	38.92		*Tellina tenuis*	3.25	54.69
Sipunculo n. id.	2.79	41.71		*Processa parva*	3.01	57.71
Nephtydidae	2.63	44.34		*Dexamine spinosa*	2.88	60.59
Nemertinea n. id.	2.22	46.56				
Branchiostoma lanceolatum	2.11	48.68				
Amphictenidae	2.08	50.76				
Dexamine spinosa	2.01	52.77				
Chamelea gallina	1.96	54.73				
Hippomedon denticulatus	1.89	56.62				
Capitellidae	1.82	58.44				
Photis cf. *longipes*	1.74	60.18				

Bray–Curtis similarity measure. Transformations were used to reduce contributions to similarity by abundant species, and therefore to increase the importance of the less abundant species in the analyses. Nematodes and macrofauna vary in abundance between single individuals and thousands of specimens between samples, so a fourth-root transformation was applied. Ordination was by cluster and non-metric multidimensional scaling (MDS; see Kruskal & Wish, 1978; Clarke & Green, 1988). Ordination was analysed with averaged samples to amenable interpretation reducing the high number of replicates in the plot. Formal significance tests for differences between before and after dredging and seasons were performed using the ANOSIM two-way crossed permutation test (Clarke & Green, 1988; Clarke, 1993). The species contributing to dissimilarities between pre- and post-dredging analysis—using data from all seasonal periods—were investigated using the similarities percentages procedure (SIMPER; see Clarke, 1993). Multivariate analyses were performed using the PRIMER 5 program.

RESULTS

Univariate measures of community structure

Variations in meiofauna evenness (J) and diversity (H') at Lagos were not significant between pre- and post-dredging communities, but the variations in other measures such as abundance (A), number of taxa (T) and biomass (B) were highly significant. Variations between seasons were significant for all measures (Figure 3A, Table 1), lower values being found during October 2000. Interactions between pre- and post-dredging and seasons showed significant variations in A and T. Univariate measures derived from meiofauna at Vilamoura showed that only T and H' varied significantly between pre- and post-dredging communities, and that all, except for T, varied significantly between seasons (Figure 3B, Table 1). However, the interactions between pre- and post-dredging and seasons revealed no significant variations.

All univariate measures derived from macrofauna data at Lagos varied significantly between pre- and post-dredging communities (with the exception of B) and between seasons (Figure 3C, Table 1). The interactions between pre- and post-dredging and seasons revealed significant variations in A and T. In relation to macrofauna at Vilamoura, no univariate measures varied significantly between pre- and post-dredging communities. By contrast, all measures, except for J, varied significantly between seasons (Figure 3D, Table 1), with higher values in October 1999. The interactions between pre- and post-dredging and seasons revealed significant variations only in T and H'.

Concerning average taxa abundance, the Phylum Nematoda was clearly the most abundant taxon present in meiofauna ($\approx 80\%$), at both Lagos and Vilamoura, generally followed by the Copepoda, Polychaeta, Turbellaria and Oligochaeta. With the exception of Copepoda and Halacaroidea, all the remaining taxa were more abundant at Lagos than at Vilamoura, as were the overall number of taxa. In both areas, all taxa decreased in abundance except for the Nemertinea and Tanaidacea at Lagos and the Bivalvia and Cumacea at Vilamoura, which showed the opposite trend. From before to after dredging, Nematoda

decreased from a mean of 293730 (±263584) to 127677 (±99623) individuals per square metre in Lagos and from 122450 (±125925) to 84000 (±86434) in Vilamoura. Only the taxa Cladocera at Lagos and Cnidaria, Gastropoda and Sipunculo at Vilamoura were registered after dredge disturbance (Table 2).

Our use of the higher level of taxonomic specification of the macrofauna allowed identification of 125 taxa, divided into 91 species, one genus, 24 families (polychaetes), one infraclass and eight unidentified taxa, during samplings at Lagos and Vilamoura. Again, Lagos showed a higher number of taxa (114) than Vilamoura (61). There was no evidence of a clear pattern of decrease in the mean abundance for all taxa in general, as observed for meiofauna, after dredge disturbance. Thus for both areas, there was a decrease in the mean abundance of specific taxa such as Nephtydidae (polychaetes), *Corbula gibba*, *Spisula solida*, *Tellina tenuis* (bivalves), amphipods in general, *Processa parva* (shrimp) and *Amphiura mediterranea* (brittle-star), and an increase in others such as Nereidae and Orbinidae (polychaetes). Species such as *Ophiura texturata* (brittle-star), *Echinocardium cordatum* (sea-urchin) and *Dexamine spinosa* and *Hippomedon denticulatus* (amphipods) showed marked decreases in mean abundance in Lagos and increases in Vilamoura after dredge disturbance (Table 3).

Meio- and macro-benthic communities in Lagos and Vilamoura registered higher values of abundance and biomass in the October sampling seasons, although such a seasonal pattern was not always clear.

Multivariate analyses of community structure

Cluster and MDS ordination of fourth-root transformed averaged data clearly showed that the pre-dredging communities clustered separately from the post-dredging ones, however the major community changes were found between seasons (Figure 4). The ANOSIM two-way crossed significance tests indicate that all are significantly different ($P < 0.01$), except for meiofauna at Vilamoura, confirming clear major changes between seasons (higher R values, Table 4). Similarities percentage analyses (SIMPER) of fourth-root transformed meiofauna and macrofauna abundances were used to determine the contributions from individual taxa to the Bray–Curtis dissimilarities between pre- and post-dredging treatment. Variations in the abundance of nematodes, copepods, polychaetes and to a lesser extent bivalves, common to Lagos and Vilamoura, accounted for most of the meiofauna dissimilarities between pre- and post-dredging communities. The average dissimilarity between pre- and post-dredging treatment was 37.58 for Lagos and 45.99 for Vilamoura (Table 5). Concerning macrofauna, higher mean dissimilarity was observed between pre- and post-dredging communities, with 77.00 for Lagos and 80.59 for Vilamoura. The taxa that most contributed to these dissimilarities differed between areas. Variations in abundance of *Ampelisca brevicornis*, *Urothoe poseidonis* and *Siphonoecetes striatus* (amphipods), *Amphiura mediterranea* (brittle-star) and *Diogenes pugilator* (hermit crab) in Lagos, and of *Amphiura mediterranea* and *Ophiura texturata* (brittle-stars), *Spisula solida* (bivalve) and Nephtydidae, Glyceridae and Nereidae (polychaetes) in Vilamoura, accounted for most of the macrofauna dissimilarity between pre- and post-dredging communities (Table 5).

DISCUSSION

Dredging activity was found to cause changes in abundance (A), number of taxa (T), evenness (J), diversity (H') and biomass (B) in the meio- and macro-benthic community structure. Changes were also found between seasons. As a general pattern, all measures showed a decrease after dredge disturbance for meiofauna and macrofauna in both areas, except for the macrofauna at Vilamoura during April and October 1999, which showed the opposite trend. Curiously, the natural changes between seasons were significantly higher than those changes resulting from short-term dredging disturbance.

These changes among the post-dredge communities are consistent with Clarke & Warwick's (1994) statement that meio- and macro-benthic communities are sensitive to anthropogenic disturbances in the marine environment. Further, they also support the conclusions of Kaiser & Spencer (1996) and Currie & Parry (1999), that fishing impact is a major factor influencing changes in the biodiversity and taxonomic composition of a community structure. Indeed, several other experimental studies of habitat disturbance by fishing have also demonstrated general decreases in community parameters. For example, Bergman & Hup (1992) showed 10–65% reductions in echinoderm, polychaete and mollusc densities after trawling. Eleftheriou & Robertson (1992) noted negative effects on heart urchin (*Echinocardium* sp.) densities. Trush et al. (1995) observed a decrease in species richness and diversity due to scallop dredging, and Currie & Parry (1996) reported a 20–30% decrease in infaunal abundance following commercial scallop dredging. A general decrease in biodiversity after dredge disturbance (short-term impact) has also been observed for oyster shell dredging (Conner & Simon, 1979), beam trawling (Kaiser & Spencer, 1996) and rapido trawling (Pranovi et al., 2000) in other regions.

In the present study, despite the general decrease in the biodiversity of both meio- and macro-benthic communities after the passage of the dredging gear, the macrofauna tended to be more affected than meiofauna, even when considering the higher discrepancies in the abundance of the latter. This is supported by several data including macrofauna length, which implies that organisms larger than the mesh size were captured. Thus, while in the Portuguese dredge fishery by-catch species with no commercial value are discarded immediately after sorting, and several studies have showed that discarded organisms may have high survival rates (Kaiser & Spencer, 1995; Gaspar et al., 2001), some organisms clearly suffered direct mortality. This probably resulted from the impact of the gear, pressure inside the net bag or even from the surface anoxia or temperature. Moreover, the average dissimilarity values (from SIMPER) obtained for macrofauna were higher than those obtained for meiofauna. The significance levels (from ANOSIM) were significantly different for macrofauna at both Lagos and Vilamoura, but only for meiofauna at Lagos; moreover the R values (from ANOSIM) were higher for macrofauna than for meiofauna. Thus we suggest that the short-term effects of dredging upon the meiofauna is mainly due to sediment redistribution rather than to actual changes to the benthic communities, as organisms may be too small to suffer any damage and/or be caught during the fishing process.

Nematoda, Copepoda and Polychaeta generally dominated the meiofauna in the pre- and post-dredging communities at Lagos and Vilamoura. Because of their high abundances, especially the dominance of the Phylum Nematoda, which represented ≈80% of total meiofauna, the Shannon–Wiener diversity for meiofauna was lower than for macrofauna. This high abundance of Nematoda has also been reported in other regions (e.g. Heip et al., 1988; Warwick et al., 1990).

For macrofauna at Vilamoura, instead of the expected reduction in the univariate measures after the dredge impact, the opposite trend was observed in April and October 1999. This is probably because Vilamoura has been a continuously disturbed area, while dredging activity had been stopped in Lagos as a response to over-fishing. Both locations are within a bivalve fishing area and had been under severe dredge-fishing impact until four years before this study. This could explain the opposite changes observed in the macrofauna for the two areas, as noted by Chícharo et al. (2002b). The increase in the univariate measures at Vilamoura after the passage of the gear might indicate more aggressive behaviour of the predator species in this long-term fished area, where predators have learned to relate the dredging activity to the availability of prey, as observed by Chícharo et al. (2003). At Liverpool Bay, Kaiser et al. (1998) mentioned a similar behaviour under similar circumstances, where the abundance of some species decreased (target and more fragile species) and others apparently increased (predators). In fact, the SIMPER results show that the taxa that most contributed to the dissimilarity between pre- and post-dredge disturbance in Vilamoura were represented by target (e.g. bivalve *Spisula solida*) and more fragile taxa (e.g. brittle-star *Amphiura mediterranea*, sea-urchin *Echinocardium cordatum*, polychaete Glyceridae and bivalve *Tellina tenuis*), and by potential predators (brittle-star *Ophiura texturata*, polychaetes Nephtydidae, Nereidae and shrimp *Processa parva*). In this case, we considered potential predators to be those scavengers, carnivores or omnivores with the capability of aggregating on the track after the passage of the dredge. Our analysis of the pre- and post-dredging abundance of macrofauna confirmed a general pattern of taxa abundance after the passage of the dredge. First, the target and more fragile taxa decreased in mean abundance, suggesting that they were caught by the gear. Second, the potential predators increased in mean abundance, suggesting that they aggregated on the track after the passage of the dredge. The exceptions were the polychaetes Nephtydidae that, despite being described as scavenging and carnivorous (Commito, 1982; Bemvenuti, 1994), appeared to be caught or damaged by the dredge. The other exception was the sea-urchin *E. chordatum*. While we expected a reduction in its mean abundance after the passage of the dredge as noted by Eleftheriou & Robertson (1992), an increase was observed.

On the other hand, at Lagos we observed that the first 13 taxa that most contributed to the dissimilarities decreased in abundance following disturbance. The majority of these taxa were found to be essentially feeders or the herbivorous: amphipods *Ampelisca brevicornis*, *Urothoe poseidonis* and *Siphonoecetes striatus*, the brittle-star *Amphiura mediterranea*, the sea-urchin *Echinocardium cordatum*, bivalves and the gastropod *Turritella communis*. From these taxa that

most contributed to this dissimilarity, we consider that the potential predators could only be the hermit crab *Diogenes pugilator* and the polychaete Nephtydidae. However, we observed that the mean abundances of these fauna also decreased after disturbance. The differences observed in the community structure as well as in the predators and preys between Lagos and Vilamoura could suggest long-term effects of dredge disturbance, although such potential effects are outside the scope of this paper.

From the analysis of the macrofauna taxa from Lagos, it appears that the amphipods *Ampelisca brevicornis*, *Urothoe poseidonis* and *Siphonoecetes striatus* and the bivalves *Mysella bidentata* and *Divaricela divaricata* were never retained on the net bag due to their large size. These species are probably spread across the sea-floor, and therefore it is probable that their abundances might increase in the areas adjacent to the dredge track. Thus, the short-term effects of dredging for meiofauna are mainly due to sediment redistribution rather than actual changes to the benthic communities, as organisms may be too small to suffer any damage and/or be caught during the fishing process. This may also apply to the smaller macrofauna.

High and significant natural changes were observed between seasons in the meio- and macro-benthic community structures. Higher abundance and biomass were registered in the October sampling seasons, although such seasonal patterns were not always clear. Naturally occurring and interrelated factors are known to influence the community structure of the benthos, such as temperature (Beukema, 1992), storms and wave or current action. There are also seasonal variations in species abundance and diversity due to the differing life cycles of different species and variable year-to-year recruitment (Bradshaw et al., 2000). In fact, the biological and physical factors, such as the few storms that were observed during the winters, the low depths of these benthic communities (subject to water turbulence) and the temperature discrepancies between seasons in the Algarve coast, could justify the seasonal variations registered for the benthic community structure.

Thus this study supports the view that Portuguese clam dredging is responsible for short-term changes in meiofauna and macrofauna community structure, including effects on non-target species and habitat destruction. However, greater significant natural changes were found between seasons, indicating that this fishing gear causes only small-scale impacts. Further studies aiming to detect short-term changes in these ecosystems should consider a comparison between these changes and the natural seasonal fluctuations to provide a degree of comparison, and to therefore better assess short-term changes.

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