ICES Journal of Marine Science, 59: 1228–1236. 2002
doi:10.1006/jmsc.2002.1310, available online at http://www.idealibrary.com on IDEAL®

Influence of mesh size and tooth spacing on the proportion of damaged organisms in the catches of the Portuguese clam dredge fishery

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Gaspar, M. B., Leitão, F., Santos, M. N., Sobral, M., Chícharo, L., Chícharo, A., and Monteiro, C. C. 2002. Influence of mesh size and tooth spacing on the proportion of damaged organisms in the catches of the Portuguese clam dredge fishery. – ICES Journal of Marine Science, 59: 1228–1236.

Experiments to assess the effect of mesh size and tooth spacing on the catch of *Spisula solida* were undertaken with the aim of determining an optimal combination of these two characteristics to minimize the dredging impact on by-catch species. However, our data showed that tooth spacing, mesh size and the interactions between these two factors did not affect the number of damaged macrofaunal individual's caught. This may be because infauna entered the dredge without passing through the space between the teeth and the mesh of the net bag closed as it was stretched by the weight of the contents, preventing the escape of the caught individuals. Thus, independently of mesh size, when the dredge is towed over the sediment, the retained individuals were injured due to abrasion between animals and/or between animals and debris. The severity of injuries inflicted by dredging on different macrobenthic species is related to their morphology and fragility.

Keywords: clam fishery, direct mortality, dredge, gear impact, tooth spacing, mesh size.

Received 7 May 2002; accepted 30 July 2002.

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Introduction

Demersal mobile fishing gears, such as dredges and beam trawls, cause a wide range of impacts on the marine environment. These gears resuspend and rework bottom sediments, move and bury boulders, reduce microtopography and may leave long-lasting grooves (e.g. Caddy, 1973; Churchill, 1989; Mayer *et al.*, 1991). Lambert and Goudreau (1996) and Tuck *et al.* (2000) recorded sediment fluidization in fished tracks. Sediment resuspension by towed gear may alter granulometry (Aschan, 1991), release nutrients (Krost, 1990) and increase oxygen consumption (Riemann and Hoffmann, 1991) with effects on phytoplankton productivity. These physical changes may also have an effect on the benthos, either directly or indirectly. Dredging and trawling damages epifaunal and infaunal species, affecting target and by-catch species, and animals that are left exposed, damaged or killed in the track. The ecological effects of this kind of fishery can be ephemeral or lead to long-term changes in community structure (e.g. Peterson *et al.*, 1987; Bergman and Hup, 1992; Eleftheriou and

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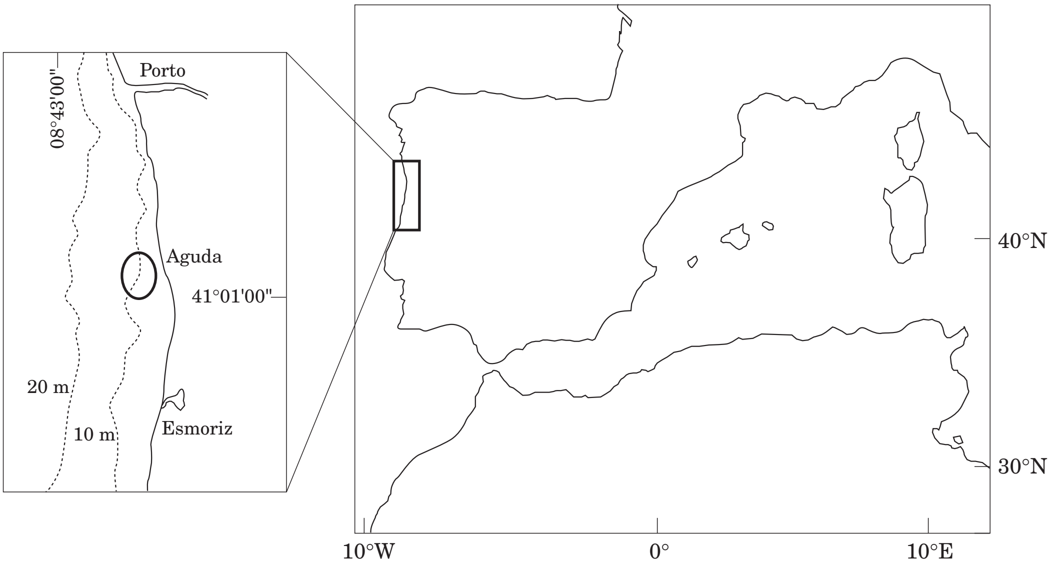


Figure 1. Map showing Portugal and the sampling area in Aguda (ellipse).

Robertson, 1992; Thrush *et al*., 1995; Currie and Parry, 1996; Kaiser *et al.*, 1998; Bergman and Santbrink, 2000) and, consequently, in food chains.

The magnitude of impacts from fishing depends on factors such as gear type, gear penetration depth into the sediment, water depth, nature of the substratum, structure of benthic communities, frequency with which the area is fished, towing speed, local environmental conditions (tidal strength and currents), and time of the year (e.g. de Groot, 1984; Churchill, 1989; Mayer *et al*., 1991).

The effective management of any living resource requires the maintenance of a dynamic balance between the benefits of exploitation and minimizing the impacts of exploitation (Brown *et al*., 1998). The impact over the benthic community may be reduced by developing new fishing gears or by improving the older ones. According to Sangster (1994), animals may be damaged by different parts of the gear, or may find certain parts of the gear more stressful than others. In the case of the Portuguese dredges, the gear features thought most likely to affect damage to macrofauna were mesh size and tooth spacing. This study assessed the effect of these two characteristics on the proportion of damaged individuals caught to determine if changes in mesh size and tooth spacing could reduce the number of macrofaunal organisms damaged or killed by dredges.

Materials and methods

Study area and fishing gear

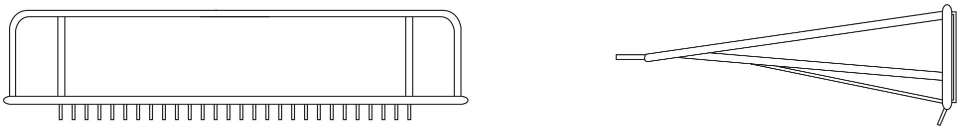
Field work was carried out during July 1999, off the northwestern coast of Portugal in the Aguda region (41°02″N and 08°41″W), one of the most important *Spisula solida* fishing grounds in this part of the Portuguese coast (Figure 1). The experiments were conducted at 8 to 10 m depth, where the commercial clam fishery generally takes place. Sediment in the study area consists of well-sorted fine-medium sands and broken shells. Currents in the area flow parallel to the shore, usually from South to North.

The experimental fishing gear (Figure 2) was similar to the commercial dredges used by the northwestern Portuguese dredge fleet. The dredge weighted approximately 80 kg and comprised a rectangular iron frame, with a toothed lower bar and a net collecting bag (approximately 4.5 m long). The gear's mouth was 193.5 cm wide and had 6.5 cm long teeth. Welded to the dredge mouth were four metal shafts where the towing cable was attached.

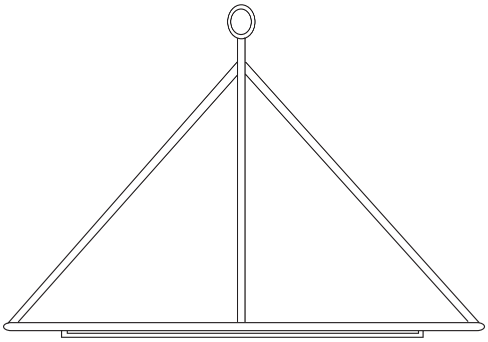
Experimental design

Fishing was undertaken by the commercial dredging vessel "*Narciso Sérgio*". Three mesh sizes (35, 40 and 50 mm stretched mesh) and three-tooth spacings (2, 4 and 6 cm) were compared. During fishing, two dredges with different mesh size and tooth spacing were towed simultaneously side-by-side. For each mesh size/tooth spacing combination, three tows were performed. Every tow was conducted for 15 min at 1.7–2.3 knots, the speed currently used by the northwestern commercial dredge fleet.

Before fishing, a cover bag with a 20 mm diamond shape mesh was attached to gear mouth. This method allowed an assessment of the proportion of damaged



Front view lateral view



Top view

Gear specifications (cm)		
Mouth frame	Total length	193.5
	Width	28.5
Tooth bar	Tooth length	6.5
	Tooth spacing	6.0
	Thickness of teeth	1.3
Metal shafts	Lateral shaft	135.5
	Internal shaft	100.0
Net bag	Total length	450.0
	Mesh size (stretched)	2.5

Figure 2. Schematic representation of the white clam *Spisula solida* north dredge.

organisms that passed trough the main net. To ensure the normal water flow through the net, the cover bag was 1.5 times longer and wider than the primary bag (Gaspar *et al.*, 1999).

On hauling, catches were sorted by taxa and a damage score was attributed to each specimen caught. The extent and type of damage was recorded following Gaspar *et al.* (2001) arbitrary scale (Table 1). To evaluate the effect of dredging on the number of damaged individuals, scores 2, 3 and 4 were used. To quantify mortality it was assumed that animals assessed as damage score 3 and 4 would die, while individuals scored as 1 and 2 would survive.

Data analysis

To evaluate the effect of tooth spacing in the number of damaged (scores 2, 3 and 4) and dead animals (scores 3 and 4) in the catch, the data obtained for the same tooth spacing were used independently from mesh size. Similarly, the effect of mesh size was studied by using hauls with the same mesh size independently of the tooth spacing. Significant differences between the effects of mesh size, tooth spacing and their interactive effects, on the proportion of damaged and dead animals, were tested using a Two-way ANOVA (F-test). Prior to ANOVA, data were analysed to test normality (Anderson Darling test) and homogeneity of variance (Bartlett's method) among treatments. Whenever these assumptions were not met, the non-parametric test of Kruskal–Wallis (K–W) ANOVA on RANKS was used. In situations where the null hypothesis was rejected, the multiple comparison test of Tukey was performed. Statistical analysis were conducted using the MINITAB software, with a significance level of $\alpha = 0.05\%$.

Results

During the experiments a total of 30 715 individuals were caught and 24 species were identified (Table 2): seven bivalve species, seven fish species, six crustacean species, two cephalopod species and one gastropod species. The most abundant species in the catches were hermit crabs *Pagurus* spp. (44%) and the target species white clam *Spisula solida* (41%). Swimming and sandy crabs composed 5% of total catches and were mainly represented by *Polybius henslowi*, *Macropipus marmoreus* and *Liocarcinus vernalis*.

The mean number caught and the proportion of damaged and dead individuals observed for each group or species and for each combination mesh size/tooth spacing is shown in Table 3. The effect of mesh size and tooth spacing on the number of damaged (scores 2, 3 and 4) and dead (scores 3 and 4) individuals was investigated for the target species *Spisula solida*, for non-target crabs (Brachyura) and for the overall community.

As far as *Spisula solida* is concerned, mesh size had no significant effect on the percentages of damaged

Table 1. Criteria used in the attribution of a damage score to each taxon.

Score	1	2	3	4
Bivalvia	In good condition	Edge of shell chipped	Hinge broken	Crushed/dead
Gastropoda	In good condition	Edge of shell chipped	Shell cracked or punctured	Crushed/dead
Cephalopoda	In good condition			Dead
Crustacea				
Anomura	In good condition	Out of shell and intact	Out of shell and damaged	Crushed/dead
Brachyura	In good condition	Legs missing/small carapace cracks	Major carapace cracks	Crushed/dead
Natantia	In good condition			Dead
Osteichthyes	In good condition	Small amount of scales missing/small cuts or wounds	Large amount of scales missing/severe wounds	Dead

Table 2. List of species present in the catches.

Bivalvia
- *Donax semistriatus* (Poli, 1844)
- *Donax venustus* (Poli, 1795)
- *Donax vittatus* (da Costa, 1778)
- *Glycymeris glycymeris* (Linnaeus, 1758)
- *Mactra corallina* (Linnaeus, 1758)
- *Spisula solida* (Linnaeus, 1758)
- *Venus fasciata* (da Costa, 1778)

Gastropoda
- *Nassarius* sp.

Cephalopoda
- *Sepia officinalis* (Linnaeus, 1758)
- *Sepiola* spp.

Crustacea
- Natantia
  - *Crangon crangon* (Linnaeus, 1758)
- Brachyura
  - *Atelecyclus undecimdentatus* (Herbst, 1783)
  - *Liocarcinus vernalis* (Risso, 1816)
  - *Macropipus marmoreus* (Linnaeus, 1758)
  - *Polybius henslowi* (Linnaeus, 1758)
- Anomura
  - *Pagurus* spp.

Osteichthyes
- *Arnoglossus laterna* (Walbaum, 1792)
- *Dicologoglossa cuneata* (Mareu, 1881)
- *Solea lascaris* (Linnaeus, 1758)
- *Solea vulgaris* (Linnaeus, 1758)
- *Trachinus vipera* (Cuvier, 1829)
- *Trigla lucerna* (Linnaeus, 1758)
- *Trisopterus luscus* (Linnaeus, 1758)

(ANOVA, F=1.50; p=0.250) or dead individuals (K–W, H=0.81; df=2; p=0.667). However, significant differences were observed when the effect of tooth spacing was tested both in terms of damaged individuals percentage (ANOVA, F=5.60; p=0.013) and dead individuals percentage (K–W, H=12.09; df=2; p=0.002). There were significant differences in the proportion of damaged individuals between tooth spacing of 40 and 60 mm (Tukey, p=0.0161), and between tooth spacing of 20 and 40 mm (Tukey, p=0.0197) in the proportion of dead individuals. However, if tooth spacing has an effect on the proportion of damaged individuals, it was expected that tooth spacing of 20 mm should damage more individuals than tooth spacing of 60 mm or vice-versa, which was not observed. Therefore, the differences found are probably related to sampling rather than to the effect of tooth spacing on the catch. No significant interactions were observed between the effects of the two factors in the percentage of damaged individuals (T-W ANOVA, F=2.18; p=0.112) and dead individuals (K–W, H=14.0; df=8; p=0.082).

In the case of crabs, the results of the two-way ANOVA analysis revealed that the percentage of damaged specimens is not affected either by tooth spacing (ANOVA, F=0.83; p=0.452), mesh size (ANOVA, F=0.72; p=0.500) or interactions between these factors (ANOVA, F=2.27; p=0.102). No significant differences were also found for the effect of mesh size (K–W, H=0.61; df=2; p=0.739), tooth spacing (K–W, H=0.91; df=2; p=0.633) and interactions between mesh size and tooth spacing in the percentage of dead crabs (K–W, H=10.49; df=8; p=0.232).

For the overall catches, non-significant differences were found in the effect of mesh size, tooth spacing and interactions between these two gear specifications in the percentage of damaged (Table 4) and dead individuals (K–W, mesh size – H=1.59; df=2; p=0.451; K–W, tooth spacing – H=3.71; df=2; p=0.156; K–W, interaction – H=7.89; df=8; p=0.444). After establishing that mesh size and tooth spacing did not have any effect on the proportion of damaged and dead individuals, data were pooled and the mean number of damaged and dead animals were obtained for a standard 15 min haul (Table 5). The analysis of Table 5 shows that the mean percentage of both damaged (4%) and dead individuals (1%) of the overall catch was very low. However vulnerability to dredging differed according to taxa, with Cephalopoda (42%), Osteichthyes (18%) and Brachyura (6%) being the most sensitive taxa to this kind of fishery. The high mean mortality observed for cephalopods can be explained by their fragile structure and small size of *Sepiola* spp.,

Table 3. Comparison of the mean number of damaged (scores 2 to 4) and dead individuals (scores 3 and 4) for each taxon and for each combination of mesh size/tooth spacing experimented.

Mesh size 35

Tooth spacing	20 mm					40 mm					60 mm				
Species/Group	Total	Damaged n	Damaged %	Dead n	Dead %	Total	Damaged n	Damaged %	Dead n	Dead %	Total	Damaged n	Damaged %	Dead n	Dead %
Bivalvia															
D. semistriatus	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
D. venustus	0.3	0.0	0.0	0.0	0.0	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
D. vittatus	5.3	0.3	6.3	0.3	6.3	2.0	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	0.0
G. glycymeris	0.3	0.0	0.0	0.0	0.0	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
M. corallina	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
S. solida	548.0	26.7	4.9	6.0	1.1	556.3	23.3	4.2	2.0	0.4	320.0	39.3	12.3	2.3	0.7
V. fasciata	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	—	0.0	—
Total	554.3	27.0	4.9	6.3	1.1	558.7	23.3	4.2	2.0	0.4	324.3	39.3	12.1	2.3	0.7
Gastropoda															
Nassarius sp.	41.0	0.0	0.0	0.0	0.0	41.3	0.0	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0
Cephalopoda	0.0	0.0	—	0.0	—	0.7	0.0	0.0	0.0	0.0	0.0	0.0	—	0.0	—
Crustacea															
Brachyura	8.3	0.7	8.0	0.3	4.0	21.7	3.0	13.8	2.0	9.2	23.3	5.7	24.3	4.7	20.0
Natantia	11.3	0.7	5.9	0.7	5.9	3.0	0.3	11.1	0.3	11.1	38.7	1.0	2.6	1.0	2.6
Anomura	362.3	2.7	0.7	0.0	0.0	166.3	2.7	1.6	0.0	0.0	270.0	6.7	2.5	0.0	0.0
Total	382.0	4.0	1.0	1.0	0.3	191.0	6.0	3.1	2.3	1.2	332.0	13.3	4.0	5.7	1.7
Osteichthyes															
T. lucerna	0.7	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
T. luscus	1.3	0.3	25.0	0.3	25.0	5.0	3.3	66.7	3.3	66.7	0.0	0.0	—	0.0	—
T. vipera	4.3	0.3	7.7	0.3	7.7	0.3	0.0	0.0	0.0	0.0	3.0	0.7	22.2	0.7	22.2
Soles	1.3	0.3	25.0	0.3	25.0	1.0	0.3	33.3	0.3	33.3	3.3	0.7	20.0	0.0	0.0
Total	7.7	1.0	13.0	1.0	13.0	7.3	3.7	50.0	3.7	50.0	6.7	1.3	20.0	0.7	10.0
Total	985.0	32.0	3.2	8.3	0.8	799.0	33.0	4.1	8.0	1.0	679.7	54.0	7.9	8.7	1.3

Mesh size 40

Tooth spacing	20 mm					40 mm					60 mm				
Species/Group	Total	Damaged n	Damaged %	Dead n	Dead %	Total	Damaged n	Damaged %	Dead n	Dead %	Total	Damaged n	Damaged %	Dead n	Dead %
Bivalvia															
D. semistriatus	0.0	0.0	—	0.0	—	0.3	0.0	0.0	0.0	0.0	0.0	0.0	—	0.0	—
D. venustus	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
D. vittatus	8.3	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	19.7	0.0	0.0	0.0	0.0
G. glycymeris	0.7	0.3	50.0	0.3	50.0	0.0	0.0	—	0.0	—	0.3	0.0	0.0	0.0	0.0
M. corallina	0.3	0.0	0.0	0.0	0.0	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
S. solida	689.7	53.3	7.7	12.7	1.8	347.0	16.3	4.7	2.0	0.6	426.3	31.7	7.4	3.0	0.7
V. fasciata	0.3	0.3	100.0	0.3	100.0	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
Total	699.3	54.0	7.7	13.3	1.9	348.3	16.3	4.7	2.0	0.6	446.3	42.0	9.4	3.0	0.7
Gastropoda															
Nassarius sp.	99.0	0.0	0.0	0.0	0.0	28.3	0.0	0.0	0.0	0.0	45.3	0.0	0.0	0.0	0.0
Cephalopoda	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—	1.7	0.7	40.0	0.7	40.0
Crustacea															
Brachyura	27.0	2.7	9.9	1.3	4.9	8.7	1.7	19.2	0.7	7.7	58.0	16.7	28.7	3.0	5.2
Natantia	3.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	89.7	2.7	3.0	2.7	3.0
Anomura	637.7	2.0	0.3	0.0	0.0	284.3	5.0	1.8	0.0	0.0	569.3	0.0	0.0	0.0	0.0
Total	667.7	4.7	0.7	1.3	0.2	298.0	6.7	2.2	0.7	0.2	717.0	19.3	2.7	5.7	0.8
Osteichthyes															
T. lucerna	0.3	0.0	0.0	0.0	0.0	2.0	1.0	50.0	1.0	50.0	0.0	0.0	—	0.0	—
T. luscus	2.7	0.3	12.5	0.3	12.5	4.0	1.3	33.3	1.3	33.3	3.3	3.3	100.0	1.3	40.0
T. vipera	4.0	1.0	25.0	1.0	25.0	3.7	1.3	36.4	1.3	36.4	2.7	0.3	12.5	0.0	0.0
Soles	1.0	0.7	66.7	0.3	33.3	1.0	0.3	33.3	0.3	33.3	4.3	0.3	7.7	0.3	7.7
Total	8.0	2.0	25.0	1.7	20.8	10.7	3.0	28.1	4.0	37.5	10.3	4.3	41.9	1.7	16.1
Total	1474.0	60.7	4.1	16.3	1.1	685.3	26.0	3.8	6.7	1.0	1220.7	66.3	5.4	11.0	0.9

Mesh size 50

Tooth spacing	20 mm					40 mm					60 mm				
Species/Group	Total	Damaged n	Damaged %	Dead n	Dead %	Total	Damaged n	Damaged %	Dead n	Dead %	Total	Damaged n	Damaged %	Dead n	Dead %
Bivalvia															
D. semistriatus	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
D. venustus	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
D. vittatus	52.7	0.3	0.6	0.3	0.6	22.3	0.0	0.0	0.0	0.0	7.3	0.0	0.0	0.0	0.0
G. glycymeris	0.3	0.0	0.0	0.0	0.0	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
M. corallina	0.7	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	—	0.0	—
S. solida	443.0	46.7	10.5	9.0	2.0	555.0	39.0	7.0	3.7	0.7	331.0	27.7	8.4	3.7	1.1
V. fasciata	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—	0.0	0.0	—	0.0	—
Total	496.7	47.0	9.5	9.3	1.9	577.7	39.0	6.8	3.7	0.6	338.3	27.7	8.2	3.7	1.1
Gastropoda															
Nassarius sp.	63.7	0.0	0.0	0.0	0.0	117.7	0.0	0.0	0.0	0.0	70.0	0.0	0.0	0.0	0.0
Cephalopoda	0.7	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	1.3	1.3	100.0	1.3	100.0
Crustacea															
Brachyura	135.3	34.0	25.1	15.3	11.3	92.7	6.3	6.8	1.3	1.4	100.3	6.7	6.6	1.0	1.0
Natantia	79.3	1.3	1.7	1.3	1.7	22.3	1.7	7.5	1.7	7.5	27.0	1.7	6.2	1.7	6.2
Anomura	941.7	1.3	0.1	0.0	0.0	849.3	0.0	0.0	0.0	0.0	456.0	0.0	0.0	0.0	0.0
Total	1156.3	36.7	3.2	16.7	1.4	964.3	8.0	0.8	3.0	0.3	583.3	8.3	1.4	2.7	0.5
Osteichthyes															
T. lucerna	0.7	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.7	0.7	100.0	0.0	0.0
T. luscus	0.0	0.0	—	0.0	—	0.7	0.3	50.0	0.3	50.0	0.0	0.0	—	0.0	—
T. vipera	0.3	0.0	0.0	0.0	0.0	6.0	1.3	22.2	0.0	0.0	5.7	0.7	11.8	0.0	0.0
Soles	0.7	0.0	0.0	0.0	0.0	3.3	0.3	10.0	0.0	0.0	1.0	0.3	33.3	0.0	0.0
Total	1.7	0.0	0.0	0.0	0.0	11.7	2.0	17.1	0.3	2.9	7.3	2.3	31.8	0.0	0.0
Total	1719.0	83.7	4.9	26.0	1.5	1672.0	49.0	2.9	7.0	0.4	1000.3	39.7	4.0	7.7	0.8

Table 4. Split-plot ANOVA for the effects of mesh size and tooth spacing on the percentage of damage individuals for overall macrobenthic community.

Source of Variation	d.f.	SS	MS	F	p
Mesh size	2	0.00073	0.000365	1.000	0.387
Tooth spacing	2	0.00175	0.000874	2.395	0.120
Mesh × tooth spacing	4	0.00348	0.000870	2.383	0.090
Residual	18	0.00657	0.000365		
Total	26	0.01250	0.000482		

Table 5. Comparison of the mean number of damaged (scores 2 to 4) and dead individuals (scores 3 and 4) for each taxon.

	Score				Total	Damage		Mortality	
Species/Group	1	2	3	4		no.	(%)	no.	(%)
Bivalvia									
Spisula solida	434.70	28.85	2.26	2.67	468.48	33.78	7.21	4.93	1.05
Donax vittatus	13.59	0.00	0.04	0.04	13.67	0.08	0.59	0.08	0.59
Venus fasciata	0.07	0.00	0.00	0.04	0.11	0.04	36.36	0.04	36.36
Donax semistratus	0.04	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Donax venustus	0.04	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Glycymeris glycymeris	0.15	0.00	0.00	0.04	0.19	0.04	21.05	0.04	21.05
Mactra corallina	0.15	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00
Total	448.74	28.85	2.30	2.78	482.67	33.93	7.03	5.08	1.05
Gastropoda									
Nassarius sp.	58.11	0.00	0.00	0.00	58.11	0.00	0.00	0.00	0.00
Cephalopoda	0.30	0.00	0.00	0.22	0.52	0.22	42.31	0.22	42.31
Crustacea									
Brachyura	44.22	5.30	0.22	3.07	52.81	8.59	16.27	3.29	6.23
Natantia	30.00	0.00	0.00	1.04	31.04	1.04	3.35	1.04	3.35
Anomura	501.85	2.26	0.00	0.00	504.11	2.26	0.45	0.00	0.00
Total	576.06	7.56	0.22	4.11	587.95	11.89	2.02	4.33	0.74
Osteichthyes									
Trisopterus luscus	0.89	0.22	0.00	0.78	1.89	1.00	52.91	0.78	41.27
Trachinus vipera	2.70	0.26	0.00	0.37	3.33	0.63	18.92	0.37	11.11
Trigla lucerna	0.63	0.07	0.00	0.11	0.81	0.18	22.22	0.11	13.58
Soles	1.52	0.19	0.00	0.19	1.90	0.38	20.00	0.19	10.00
Total	5.74	0.74	0.00	1.44	7.92	2.18	27.53	1.44	18.18
Total	1088.96	37.15	2.52	8.57	1137.20	48.24	4.24	11.09	0.98

which were probably killed by the weight of catch on hauling or even during sorting. Among fishes, the pouting *Trisopterus luscus*, was the most affected species. Over 10% of all flatfishes (*Dicologoglossa cuneata*, *Solea vulgaris*, *S. lascaris* and *Arnoglossus laterna*) that were retained in the net bag had a large amount of scales missing and severe wounds. Approximately 10% of the crabs caught had missing legs, while 0.4% showed major carapace wounds. Within bivalvia, the most affected species were *Venus fasciata* (36%) and *Glycymeris glycymeris* (21%), both of which were caught in low numbers. The other bivalve species caught (*Donax vittatus*, *D. semistriatus*, *D. venustus* and *Mactra corallina*) were highly resilient to the effects of dredging. The shells of the gastropods and hermit crabs provided good protection against mechanical damage, hence 100% were in perfect condition or only slightly damaged. During sorting on board, it was observed that shrimps were either in perfect condition (score 1) or dead (score 4), which may be related to the time they were retained in the net during hauling.

Discussion

Experiments were undertaken to determine the optimal combination of mesh size and tooth spacing to minimize the impact on bycatch. We expected that the number of injured animals would be affected by increasing or decreasing mesh size or tooth spacing. However, the range of mesh size and tooth combinations we tested had no effect on the numbers of damaged macrofauna caught. This may be related to the way this gear is operated, as observed by divers during the experimental phase of this work. The tooth bar of the dredge penetrated 10 cm into the sediment, acting as a rake that pushed sand to the front of the mouth frame creating a ''sand wave''. As a result infauna enters the dredge without passing through the space between the teeth. The mesh of the net bag closed as it was stretched due to the weight of the material in the bag, preventing the escape of individuals from the bag. Therefore, independently of mesh size, retained individuals were susceptible to injury due to the abrasion between animals and/or between animals and debris (empty shells) inside the bag. Thus, the probability of the retained animals becoming injured increases with tow duration (Gaspar *et al*., 1998), especially in the case of fishes (Van Beek *et al*., 1990).

The nature of the bottom can also affect the mortality induced by mobile fishing gears on benthic species. Several authors (e.g. Hall, 1994; Currie and Parry, 1996; Jennings and Kaiser, 1998; Kaiser *et al*., 1998; Franceschini *et al*., 1999) have noted that the impact of towed gears is lower on mobile sandy sediments, than on rocky, muddy or dirty bottoms (high amount of debris). On these kinds of grounds the net fills with mud or stones, which damage the catch during fishing and sorting operations. Houghton *et al.* (1971) observed that in hauls performed on sandy grounds the extent of damage inflicted to invertebrate species varied with the quantity of empty shells caught. In silty seabed total mortality, including the mortality inflicted by the passage of the trawl over the seabed is higher than in sandy sediments, due to larger penetration depth of the gear (Bergman & Santbrink, 2000). However, in the Portuguese dredge fishery, the nature of the bottom is not a significant factor as the exploited species only form extensive and dense beds on clean sandy bottoms (Gaspar, 1996).

The severity of injuries inflicted by dredging on different macrobenthic species is related to their morphology and fragility. For instance, whelks (*Nassarius* sp.) and hermit crabs (*Pagurus* spp.) were highly resistant to the effects of entrapment in the net bag. These species are protected by a strong shell that provides an efficient protection against fishing operations. Low mortalities were also observed for the crabs *Atelecyclus undecimdentatus*, *Liocarcinus vernalis*, *Macropipus marmoreus* and *Polybius henslowi*, which accords with the findings of Kaiser and Spencer (1995) for other crab species. A high proportion of the *Spisula solida* and *Donax vittatus*, the most abundant bivalve species in this area, were undamaged, as these species are well protected by their thick shells. In contrast, Cephalopoda and Osteichthyes were frequently damaged. The high mortalities found for *Sepiola* spp. was probably related to their small size and soft structure. These animals were probably killed by the weight of catches on hauling the net or during sorting operations. De Groot and Apeldoorn (1971) also observed that cephalopods were easily damaged during fishing. Among fishes, the most vulnerable species was *Trisopterus luscus*. However, cuttlefish and fish were only caught in low numbers. The results reported here agree with Hall-Spencer *et al.* (1999) and Franceschini *et al.* (1999) for bivalves and gastropods. However, in the case of badly damaged and dead crabs and cephalopods, we found out a significantly smaller impact than those authors. For commercial beam trawls, de Groot and Lindeboom (1994) reported mortalities up to 50% for most crabs and molluscs. In the present study, most animals present in the catches were apparently very resistant to the fishing process, certainly explaining the low number of severely damaged and dead individuals (1%) found for the overall macrobenthic community. This may indicate that any vulnerable species have been removed by dredging long ago.

In the northwestern fishery by-catch is discarded immediately after sorting, which is an important stage for the organisms' survival, since exposure to air inevitably causes stress and mortality if sorting times are long and conditions on deck unfavourable (Medcof and Bourne, 1964; Gaspar and Monteiro, 1999). According to McLoughlin *et al.* (1991) damage is directly correlated with dredge catch efficiency. In the present work we did not gather data on dredge efficiency, however we believe that the efficiency of this gear is relatively low since *in situ* and video observations of clam dredging showed that shortly after the start of the tow, a sand buffer is formed in front of the gear mouth, pushing sediment sideways and above the dredge, limiting the amount of material that enters the net bag. Therefore, it is likely that animals that make contact with the dredge but are not caught may become damaged dying immediately or become susceptible to predation dying subsequently.

Taking into consideration the species vulnerability, the fishing strategy used by the local dredge fleet and the results of the bivalve surveys carried out periodically by IPIMAR since 1986, we can speculate about the long-term effects of this kind of fishery over the macrobenthic community. Due to the rough sea conditions observed all year round, the northwestern dredge fleet only operates during 5–6 months per year. Fishing effort is distributed both spatially and seasonally, so its effects on the benthos also vary in space and time. The fleet concentrates fishing effort during short periods on a specific *Spisula solida* beds, until catch rates drop below economically acceptable levels, after which the clam bed remains unfished for periods up to 2 years. This fact leads to a highly patchy distribution of fishing effort and so we cannot talk about continuous and cumulative fishing effects for a specific white clam bed and associated community. The immediate effect of the fishing process is the reduction of the target species abundance. However, the fishing process also inevitably damages other macrobenthic species present in the area, and would be expected to decrease the abundance of the most vulnerable non-target species. It is interesting to emphasize that the same species found in the present work have been recorded in the bivalve surveys carried out since 1986, which indicates that during this period the macrobenthic species composition present in the area where this study was undertaken, remained unchanged. Although some changes in abundance occurred, we do not know if these changes were due to the fishing, due to natural causes or a result of the combination of both factors. Nevertheless, we believe that the impact of this type of fishery upon the macrobenthic community could be minimized by developing a more efficient and, simultaneously, more selective dredge, in order both to reduce the number of non-target individuals in the catch and to allow the escape of bycatch during the tow. Gaspar *et al.* (2001) showed that in *Callista chione* dredge fishery bycatch was significantly reduced ($\approx 50\%$) when the net bag was replaced by a metallic grid to retain the catch. We think that this gear modification should also be adopted in the *Spisula solida* northwestern Portuguese dredge fishery.

Acknowledgements

We would like to thank Dr Paulo Vasconcelos and two other anonymous referees whose suggestions greatly improved the manuscript. We also thank Augusto Pombal, Laurinda Paiva, Nelson Almeida, Paulo Castro, Rolando Machado, Tibério Simoes and Vitor Bettencourt, for technical assistance during field work and sample processing, and the crew of the commercial dredging boat "*Narciso Sérgio*" for their skilful handling of the boat and the gears. This study was in part funded by European Commission (FAIR CT-98-4465; Project ECODREDGE).

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