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# A comparison of direct macrofaunal mortality using three types of clam dredges

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The white clam *Spisula solida* is harvested along the entire coast of Portugal using mechanical dredges. In this study, the total direct mortality of the macrobenthic community caused by three types of clam dredges (north dredge—ND, traditional dredge—TD, and the metallic grid dredge—GD) used in the *S. solida* fishery was determined and compared. The relationship between mortality and catching efficiency for each type of dredge was also assessed. Our results showed significant differences for total direct mortality between the ND and both the GD and TD dredges. This difference was largely attributed to the mortality of animals that died in the dredge track as a direct result of the physical damage inflicted by the dredge passing. It was also found that the damage to uncaught individuals is directly related to gear efficiency. The lower catching efficiency of the ND (64%) led to a higher proportion of damaged individuals being left in the dredge path, when compared with the more efficient GD (98%) and TD (90%) dredges. Short and long-term implications of the impact of dredging on the composition of benthic communities are discussed. From fisheries management and ecological points of view, there are obvious advantages to introduce into the bivalve dredge fisheries more efficient and selective dredges in order to reduce the number of damaged individuals and by-catch, and consequently decreasing the impact on the macrobenthic communities.



Keywords: direct mortality, dredge, fishing impacts, gear efficiency, macrofauna, *Spisula solida*.

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## Introduction

The exploitation of subtidal bivalve beds along the Portuguese coast is relatively recent, having been initiated only in the late 1960s. Although several species of commercial importance are harvested, only the white clam *Spisula solida* is caught by the whole dredge fleet, as it is the only species that occurs along the entire Portuguese continental coast. For management purposes the Portuguese coast was divided into three main fishing areas, the northwest, the southwest and the southern areas. These were defined based on the distribution of clam beds and fishing ports, the coastal topography and environmental conditions. Although the majority of technical measures used to manage the fishery are similar in all three fishing areas, there are differences relating to the number of fishing licenses, boat engine power and daily quotas per boat and species. In this fishery, only mechanical dredges are allowed, made up of a rigid iron structure with a toothed lower bar, and a collecting system. The main differences between the dredges used in the *S. solida* fishery relate to the shape and length of the dredge mouth and the collecting system. Figure 1 shows photographs of the three types of dredges used in the fishery. Until 1999, the northwest dredge fleet only operated with the north dredge (ND) and the southwest and south dredge fleets with the traditional dredge (TD). Recently, a new dredge design (grid dredge—GD) was introduced into the fishery and since then

 

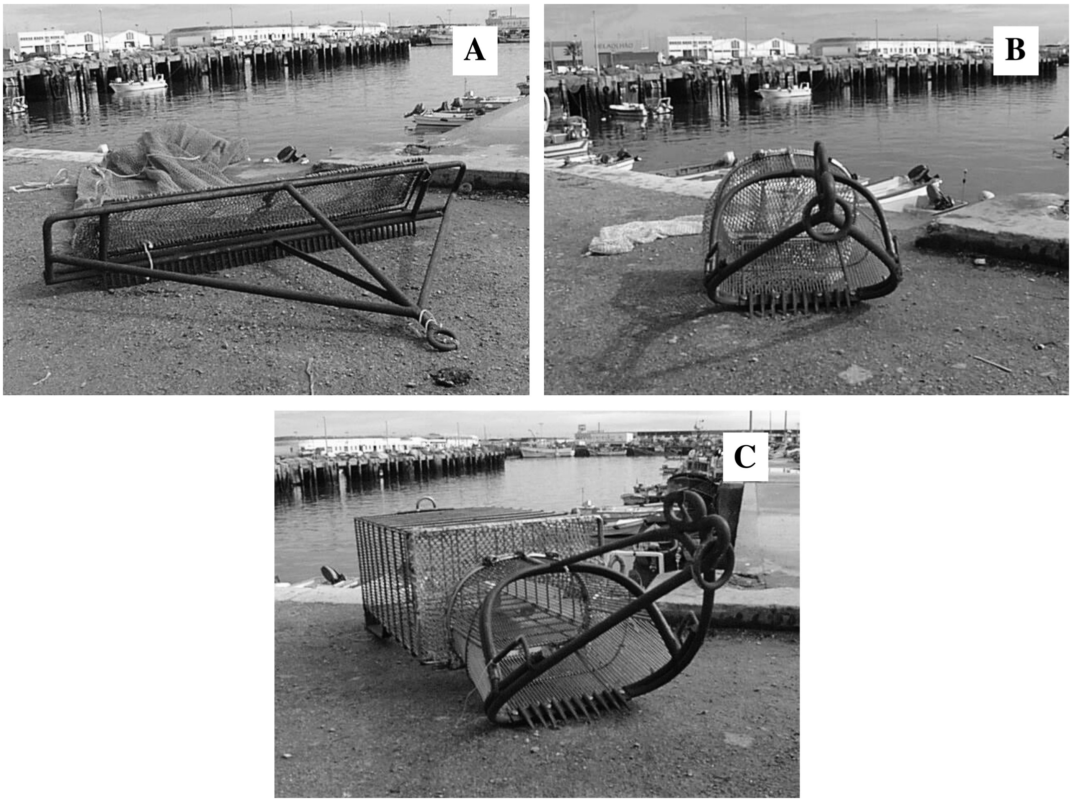


Figure 1. Photographs of the three dredge types used in the *S. solida* Portuguese fishery. (A) North dredge (ND); (B) traditional dredge (TD); (C) grid dredge (GD).

the majority of the fleet operating along the southwest and south coasts of Portugal have started using this new gear. This dredge employs a metallic grid instead of using a net bag to retain the catch. Due to the extra weight of the GD only small boats still use the TD.

These dredges were designed to dig clams out of the sediment, impacting on the benthic habitat, both in terms of its physical structure and its biological communities. Direct impacts include scraping and ploughing of the substrate, sediment re-suspension, destruction of the benthos and loss of biodiversity (e.g. Van Dolah *et al*., 1987; Eleftheriou and Robertson, 1992; Jones, 1992; Currie and Parry, 1996; Kaiser *et al*., 1996; Collie *et al*., 1997; Bergman and van Santbrink, 2000). Although the impact on the sediment caused by the three dredge types used in the *S. solida* fishery is expected to be similar (capture methods being identical), the impact on the macrofauna may be different. In order to introduce modifications to the dredges to reduce the mortality, or even to ban dredge types that cause greater impacts, it is important to estimate the direct mortality induced by each dredge type on the benthic macrofauna. During this study, the direct effects of three different dredge types on macrobenthic mortality were compared. The relationship between this mortality and the catching efficiency for each type of dredge was also assessed.

# Materials and methods

## Experimental design

The study was undertaken in June 2001 in the Sines region on the southwestern coast of Portugal. The site is off Lagoa de Santo André (38°02′99″N, 08°49′78″W), and is one of the most important fishing grounds for *S. solida* in Portugal. The samples were collected from sandy bottoms between 8 and 10 m depth. The study was carried out using the research vessel “Donax”, which is of similar size and engine power to local commercial fishing boats. The dredges were identical to those used by the commercial dredge fleet. Throughout this study the dredge usually employed in the northwest coast of Portugal was referred to as a north dredge (ND), the dredge used by small boats was referred to as a traditional dredge (TD), while the dredge fitted with a metal grid collecting system was referred to as a grid dredge (GD). Table 1 summarises the gear specifications of these dredges.

A total of 12 tows were undertaken, four for each dredge type. Dredges were towed for 5 min at a mean speed of 1.5 knots. Both the tow duration and fishing speed used in this experiment were similar to those used by commercial fishing vessels operating with these types of dredge. The duration of dredge hauls was measured from the time the

Table 1. Gear specifications of the dredges used in this study.

| | North dredge | Grid dredge | Traditional dredge |
|---|---|---|---|
| Anterior part | | | |
| Length of the mouth (cm) | 150 | 64 | 64 |
| Space between rods (cm) | – | 0.8 | 0.8 |
| Number of teeth | 49 | 10 | 10 |
| Space between teeth (cm) | 2 | 2.2 | 2.2 |
| Tooth length (cm) | 12 | 15 | 15 |
| Tooth angle (degrees) | 20° | 20° | 20° |
| Net bag | | | |
| Length (cm) | 450 | – | 250 |
| Mesh size (mm) | 25 | – | 25 |
| Grid | | | |
| Space between rods (cm) | – | 1.2 | – |

winch stopped paying out the towing cable to the time when the winch was restarted.

In order to determine the proportion of damaged individuals that entered the dredge but passed through the net bag during the fishing operation and during dredge retrieval, the cover method was adopted. This involves covering the net bag or grid with a second net bag with a smaller mesh size (20 mm mesh). The cover bag was stretched loosely over the entire back of the dredges, enough slack being left in the cover to reduce any masking effect on selection and to allow the natural flow of water through the net as suggested by Gaspar *et al*. (1999). The catches of each dredge, coming from the bag or the grid and from the cover, were always processed separately. In order to estimate macrofaunal mortality induced by each dredge, the extent of damage sustained was recorded for each organism caught using a 4 score scale (Table 2). This was visually assessed by the same person on all occasions immediately after sampling operations on board.

Diving surveys were also conducted in order to estimate the percentage of damaged macrofaunal individuals left on dredge tracks, to determine the length of the dredge path and to estimate the dredges efficiency of capture. The efficiency of capture is defined as the proportion of the number of target clam species in the path of the dredge that enters through the dredge mouth (Caddy, 1971). For each haul, divers randomly collected 54 sediment samples using quadrats (area $= 0.0625\ \mathrm{m}^2 \times 0.15\ \mathrm{m}$ depth) within the dredge path: 27 quadrats in the furrow and 27 in the ridge. Samples were sieved *in situ* through a 5 mm mesh bag, and when back on board the boat, preserved in 70% ethanol. In the laboratory, the organisms were identified, counted, weighed and a damage score was attributed to each specimen caught using the damage scale (Table 2). The species identification was made according to Bucquoy *et al*. (1882–1898), Tebble (1966), FAO (1987) and Poppe and Goto (1993). The nomenclature adopted was that of FAO (1987).

## Data analysis

The PRIMER© software package (Clark and Warwick, 1994) was used to compare methods of capture (grid vs mesh), by investigating the number of individuals per species that escaped through the meshes of the bag (ND and TD) or through the bars of the grid (GD). Abundance data from the cover bag was square-root-transformed prior to cluster analysis using the Bray–Curtis method to produce a similarity matrix. The relationships between samples were examined by non-metric multidimensional ordination plots (MDS), while the analysis of similarities (ANOSIM) routine (Clark and Warwick, 1994) was used to detect any strong difference on dredge selectivity.

Analyses of variance (ANOVA) or Kruskal–Wallis ANOVA were used to investigate differences between the fishing yields obtained from each dredge and to test the effect of dredge design on the proportion of damaged and dead individuals. The damage inflicted by dredges on macrofauna was analysed separately for the individuals that entered the dredge and for those organisms left on the dredge path. Multiple comparisons were performed using the Student–Newman–Keuls test. Prior to the application of ANOVA or Kruskal–Wallis ANOVA, data were standardised and transformed to arcsine square root values when

Table 2. Criteria used in the attribution of a damage score for 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 |
| Echinoidea | In good condition | <50% spine loss | >50% spine loss/minor cracks | Crushed/dead |
| Ophiuroidea | In good condition | Arms missing | Worn and arms missing/minor disc damage | Major disc damaged/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 |
| Osteichthyes | In good condition | Small amount of scales missing/small cuts or wound | Large amount of scales missing/severe wounds | Dead |

expressed as a percentage. Statistical analyses were undertaken using SIGMASTAT© statistical software.

## Results

A total of 29,119 individuals belonging to eight taxa were caught during the fishing experiments (Table 3). The catches from the GD, TD and ND comprised 52.9, 37.4 and 9.7% of the total number of individuals caught, respectively. Bivalvia was the taxon most represented with eight species, followed by Osteichthyes and Brachyura, with four and three species, respectively. Apart from the target species *S. solida*, the most abundant species were the bivalves *Donax vittatus*, *Tellina tenuis* and *Ensis siliqua*, the crabs *Atelecyclus undecimdentatus* and *Liocarcinus depurator*, and the heart urchin *Echinocardium cordatum*.

From Table 3 it can be observed that the ND and the TD retained almost all individuals that entered the dredge (93.9 and 97.1%, respectively), while the GD retained a smaller proportion of individuals (76.1%). Cluster analysis and subsequent multidimensional scaling (MDS) applied to abundance data from all samples collected from the cover bag revealed two main groupings of points (Figure 2). One group corresponded to the GD and the other group contained the ND and TD. The ANOSIM test that accounted for retention type effects (grid vs mesh bag) showed significant differences between the GD and both the TD and ND ($r = 0.969$, $P < 0.001$), reflecting differences on the selectivity of these fishing gears.

Table 4 summarises the data concerning the mean percentage of damaged (scores 2–4) and dead individuals (scores 3 and 4) that entered the dredges. Although the mean percentage of both damaged and dead individuals in the overall catch is very low, it was observed that the ND damages and kills a slightly lower proportion of individuals (mean damaged = 3.3%; mean mortality = 2.5%) than the GD (mean damaged = 5.0%; mean mortality = 4.8%) and the TD (mean damaged = 7.4%; mean mortality = 5.9%). However, the statistical analysis carried out showed that gear type had no effect on the percentage of damaged individuals (ANOVA, $F = 1.48$, $P = 0.240$) or dead individuals (K–W, $H = 5.538$, $df = 2$, $P=0.057$). Within the more abundant species, it was observed that those most affected by this kind of fishery were the thin-shelled bivalves *E. siliqua* and *T. tenuis*, the heart urchin *E. cordatum* and the crab *A. undecimdentatus*.

The scuba-diving surveys allowed an estimate of the efficiency of capture of the dredges. For the ND an efficiency of capture of 64% was estimated and the incidental mortality on uncaught white clams was in the range 5–20%. Higher efficiencies of capture were estimated for both the GD (98%) and TD (90%), while for both dredges no damage on the uncaught white clams was observed. It is interesting to note that higher catch efficiencies lead to a lower proportion of damaged individuals that are left in the path of the dredge. In Table 5, it can be seen that the ND damages and kills a higher proportion of the uncaught individuals than the GD and TD.

The mean percentage of both damaged and dead uncaught individuals from the TD was also found to be

Table 3. Total number of individuals that entered the dredges and retained in the cover bag.

| | | North dredge | | Grid dredge | | Traditional dredge | |
|---|---|---|---|---|---|---|---|
| | Species | Total | Cover | Total | Cover | Total | Cover |
| Polychaeta | Polychaeta | | | 12 | 12 | 5 | 0 |
| Bivalvia | *Donax trunculus* | 1 | 1 | | | | |
| | *Donax vittatus* | 309 | 89 | 1392 | 1385 | 1441 | 152 |
| | *Dosinia exoleta* | | | 2 | 0 | | |
| | *Ensis siliqua* | 2 | 1 | 117 | 110 | 45 | 0 |
| | *Mactra corallina stultorum* | 1 | 0 | 33 | 9 | 19 | 0 |
| | *Spisula solida* | 2347 | 31 | 12211 | 1343 | 8484 | 91 |
| | *Tellina tenuis* | 11 | 10 | 640 | 638 | 87 | 47 |
| | *Venus striatula* | | | 5 | 5 | 2 | 0 |
| Cephalopoda | *Sepia officinalis* | | | | | 2 | 0 |
| Anomura | *Pagurus* spp. | 4 | 4 | 5 | 2 | | |
| Brachyura | *Atelecyclus undecimdentatus* | 61 | 10 | 705 | 47 | 478 | 2 |
| | *Leucarcinus depurator* | 39 | 20 | 150 | 129 | 295 | 28 |
| | *Polybius heslowi* | 4 | 1 | 21 | 2 | 14 | 0 |
| Echinoidea | *Echinocardium cordatum* | 25 | 4 | 120 | 7 | 12 | 0 |
| Ophiuroidea | *Ophiura texturata* | 1 | 1 | | | | |
| Osteichthyes | *Citharus linguatula* | 1 | 0 | | | 2 | 0 |
| | *Dicologoglossa cuneata* | | | | | 5 | 0 |
| | *Trachinus draco* | 1 | 1 | | | | |
| | *Trachinus vipera* | 7 | 1 | | | | |
| | Total | 2815 | 174 | 15413 | 3689 | 10891 | 321 |

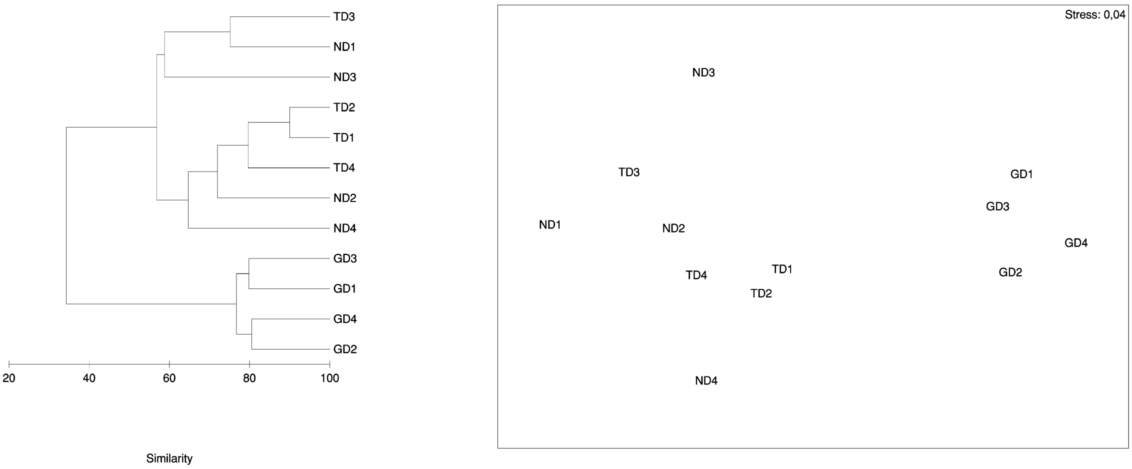


Figure 2. Bray–Curtis cluster analysis and Multidimensional Scaling Ordination (MDS) plot from cover bag data. ND, north dredge; TD, traditional dredge; GD, grid dredge.

higher than those obtained from the GD. The results of one-way ANOVA showed that gear type has an effect on both the percentage of damaged ($F = 10.114$, $P = 0.005$) and dead ($F = 4.341$, $P = 0.048$) individuals left on the dredge track. A Student–Newman–Keuls multiple pairwise comparison showed significant differences between the ND and both the GD and TD, both in terms of damaged and dead individuals. Within the dredge tracks, bivalve species were the most abundant group, comprising nearly 100% of the total number of macrofaunal individuals collected. Among these, *T. tenuis* was the most affected species followed by *D. vittatus*.

Fishing yield is known to be directly related to the efficiency of capture of dredge gears and therefore differences in the mean fishing yield (kg/5 min tow) obtained for each dredge were observed. From Figure 3 it can be seen that the mean fishing yield registered both for the GD and TD was substantially higher than that observed for the ND. The one-way ANOVA analysis performed revealed significant differences ($F = 16.486$, $P = 0.004$) in the mean fishing yield obtained for the dredges assayed. Application of the Student–Newman–Keuls test showed the existence of significant differences in the mean fishing yield (S–N–K, $P < 0.05$), between the GD and ND, and between the TD and ND.

Finally, for each dredge and tow, data from the bag, cover and dredge path were pooled in order to estimate and compare total mortality. Table 6 summarises the data obtained for each dredge and tow in terms of the percentage of damaged and dead individuals. Data analysis shows that for the overall community the ND damages and kills a higher proportion of macrofaunal individuals than the GD and TD. The Kruskal–Wallis one way ANOVA on Ranks revealed the existence of significant differences both in terms of damaged (K–W, $H = 8.769$, $df = 2$, $P = 0.001$) and dead individuals percentage (K–W, $H = 6.615$, $df = 2$, $P = 0.024$). The Student–Newman–Keuls Pairwise Multiple Comparison showed significant differences ($P < 0.05$) between the ND and both the GD and TD for damaged and dead individuals.

## Discussion

The direct mortality on the macrobenthic community inflicted by three types of clam dredges used in the *S. solida* fishery was both determined and compared in this study. Total direct mortality was assessed, taking into consideration the degree of damage sustained by individuals that entered the dredges, plus those individuals damaged and left in the dredges path. Our results showed significant differences in total direct mortality between the north dredge and both the grid and traditional dredges. These differences were largely attributed to the animals in the dredge track that died as a direct result of physical damage inflicted by the dredge passing. It was found during the study that damage on uncaught individuals was directly related to gear efficiency. The lower catching efficiency of the north dredge led to a higher proportion of damaged individuals left in the dredge track, when compared with the more efficient grid and traditional dredges. This relationship between catching efficiency and damage has also been observed by other authors. Meyer *et al*. (1981) reported that when the efficiency of dredges was low, larger clams, which burrowed deeper into the sediment, suffered mortalities as high as 92%, and when efficiency was high, mortalities decreased to 30%. Caddy (1973) noted that the low efficiency of the Alberton dredge was responsible for causing a high amount of lethal and sublethal damage to scallops left in the dredge's track. This amount of damage was also found to be higher on more rough seabeds. McLoughlin *et al*. (1991) concluded that in addition to its low catching efficiency, the Australian mud dredge

Table 4. Mean number and mean proportion of individuals damaged and killed that entered the dredges, for each taxon and gear type.

| | North dredge | | | | | Grid dredge | | | | | Traditional dredge | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Damaged | | Mortality | | | Damaged | | Mortality | | | Damaged | | Mortality | |
| | Total | *N* | (%) | *N* | (%) | Total | *N* | (%) | *N* | (%) | Total | *N* | (%) | *N* | (%) |
| Polychaeta | | | | | | | | | | | | | | | |
| Polychaeta | | | | | | 2.93 | 0.59 | 20.00 | 0.59 | 20.00 | 1.17 | 0.59 | 50.00 | 0.59 | 50.00 |
| Bivalvia | | | | | | | | | | | | | | | |
| *Donax trunculus* | 0.31 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | | | | | | |
| *Donax vitattus* | 77.18 | 3.37 | 4.37 | 3.37 | 4.37 | 348.05 | 25.78 | 7.41 | 25.20 | 7.24 | 360.35 | 28.13 | 7.80 | 26.95 | 7.48 |
| *Dosinia exoleta* | | | | | | 0.59 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | |
| *Ensis siliqua* | 0.61 | 0.61 | 100.00 | 0.61 | 100.00 | 29.30 | 22.27 | 76.00 | 22.27 | 76.00 | 11.13 | 9.38 | 84.21 | 9.38 | 84.21 |
| *Mactra corallina stultorum* | 0.31 | 0.00 | 0.00 | 0.00 | 0.00 | 8.20 | 4.69 | 57.14 | 4.10 | 50.00 | 4.69 | 2.34 | 50.00 | 2.34 | 50.00 |
| *Spisula solida* | 586.78 | 11.03 | 1.88 | 5.82 | 0.99 | 3052.73 | 41.60 | 1.36 | 35.74 | 1.17 | 2121.09 | 87.30 | 4.12 | 55.66 | 2.62 |
| *Tellina tenuis* | 2.76 | 0.31 | 11.11 | 0.31 | 11.11 | 159.96 | 10.55 | 6.59 | 10.55 | 6.59 | 21.68 | 4.69 | 21.62 | 2.93 | 13.51 |
| *Venus striatula* | | | | | | 1.17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.59 | 0.00 | 0.00 | 0.00 | 0.00 |
| Cephalopoda | | | | | | | | | | | | | | | |
| *Sepia officinalis* | | | | | | | | | | | 0.59 | 0.59 | 100.00 | 0.59 | 100.00 |
| Anomura | | | | | | | | | | | | | | | |
| *Pagurus* spp. | 0.92 | 0.00 | 0.00 | 0.00 | 0.00 | 1.17 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | |
| Brachyura | | | | | | | | | | | | | | | |
| *Atelecyclus undecimdentatus* | 15.31 | 3.68 | 24.00 | 3.68 | 24.00 | 176.37 | 63.87 | 36.21 | 63.28 | 35.88 | 119.53 | 37.50 | 31.37 | 35.16 | 29.41 |
| *Leucarcinus depurator* | 9.80 | 0.92 | 9.38 | 0.61 | 6.25 | 37.50 | 7.62 | 20.31 | 7.62 | 20.31 | 73.83 | 26.95 | 36.51 | 22.85 | 30.95 |
| *Polybius heslowi* | 0.92 | 0.61 | 66.67 | 0.61 | 66.67 | 5.27 | 2.93 | 55.56 | 2.93 | 55.56 | 3.52 | 2.34 | 66.67 | 2.34 | 66.67 |
| Echinoidea | | | | | | | | | | | | | | | |
| *Echinocardium cordatum* | 6.13 | 2.14 | 35.00 | 2.14 | 35.00 | 29.88 | 12.89 | 43.14 | 12.89 | 43.14 | 2.93 | 1.76 | 60.00 | 1.76 | 60.00 |
| Ophiuroidea | | | | | | | | | | | | | | | |
| *Ophiura texturata* | 0.31 | 0.31 | 100.00 | 0.31 | 100.00 | | | | | | | | | | |
| Osteichthyes | | | | | | | | | | | | | | | |
| *Citharus linguatula* | 0.31 | 0.31 | 100.00 | 0.31 | 100.00 | | | | | | 0.59 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Dicologoglossa cuneata* | | | | | | | | | | | 1.17 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Trachinus draco* | 0.31 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | | | | | | |
| *Trachinus vipera* | 1.84 | 0.00 | 0.00 | 0.00 | 0.00 | | | | | | | | | | |
| Total | 703.76 | 23.28 | 3.31 | 17.76 | 2.52 | 3853.13 | 192.77 | 5.00 | 185.16 | 4.81 | 2722.85 | 201.56 | 7.40 | 160.55 | 5.90 |

Table 5. Mean number and mean proportion of damaged and dead individuals left in the dredge path, for each taxon and gear type.

| | North dredge | | | | | Grid dredge | | | | | Traditional dredge | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Damaged | | Mortality | | | Damaged | | Mortality | | | Damaged | | Mortality | |
| | Total | *N* | % | *N* | % | Total | *N* | % | *N* | % | Total | *N* | % | *N* | % |
| Bivalvia | | | | | | | | | | | | | | | |
| *Donax vitattus* | 147.00 | 0.00 | 0.00 | 0.00 | 0.00 | 17.33 | 0.00 | 0.00 | 0.00 | 0.00 | 75.33 | 58.00 | 76.99 | 58.00 | 76.99 |
| *Spisula solida* | 326.00 | 146.67 | 44.99 | 33.33 | 10.22 | 58.00 | 0.00 | 0.00 | 0.00 | 0.00 | 233.33 | 0.00 | 0.00 | 0.00 | 0.00 |
| *Tellina tenuis* | 402.00 | 217.67 | 54.15 | 217.67 | 54.15 | 1170.67 | 208.67 | 17.82 | 208.67 | 17.82 | 1060.67 | 300.67 | 28.35 | 185.33 | 17.47 |
| Anomura | | | | | | | | | | | | | | | |
| *Pagurus* spp. | | | | | | | | | | | 4.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Brachyura | | | | | | | | | | | | | | | |
| *Atelecyclus undecimdentatus* | | | | | | 2.00 | 2.00 | 100.00 | 2.00 | 100.00 | | | | | |
| Echinoidea | | | | | | | | | | | | | | | |
| *Echinocardium cordatum* | 6.00 | 6.00 | 100.00 | 6.00 | 100.00 | | | | | | 1.33 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 881.00 | 370.33 | 42.04 | 257.00 | 29.17 | 1248.00 | 210.67 | 16.88 | 210.67 | 16.88 | 1374.67 | 358.67 | 26.09 | 243.33 | 17.70 |

damages many more scallops than it catches, producing a post-fishing mortality rate seven times the estimated natural mortality rate for *Pecten fumatus*. However, it should also be emphasised that the maximum dredging impact may not occur immediately after dredging, as exposed organisms may be predated. The attraction of epifaunal scavengers and predators to fished areas has been recorded in other studies (e.g. Meyer *et al*., 1981; Kaiser and Spencer, 1994; Lambert and Goudreau, 1996; Ramsay *et al*., 1996; Bergman and van Santbrink, 2000). Analysis of the diet composition of scavengers collected from trawled areas indicated that they feed primarily on animals that were damaged or disturbed by the trawl (Kaiser and Spencer, 1996).

As well as direct mortality from being caught and indirect mortality due to predation on uncaught clams, there may be further mortality on discarded individuals (Veale *et al*., 2000), especially if sorting times are long and conditions on deck are unfavourable (Medcof and Bourne, 1964). Furthermore, re-location into unsuitable habitat and predation while returning to the seafloor after being discarded from the ship's deck may also contribute to increased mortality (Gaspar, 1996). This type of mortality also depends on many conditions, such as depth, type of species, individual's size, degree of damage and predator concentration. Gaspar and Monteiro (1999) reported that the length of exposure to air on deck was directly related to juvenile *S. solida* mortality. Robinson and Richardson (1998) found that undersized *Ensis arcuatus* individuals returned to the seabed were slow to re-bury, becoming highly vulnerable to attack from predatory crabs. These two examples illustrate the importance of designing more highly selective dredges. Our results showed that the GD retained a significantly smaller proportion of captured individuals than the TD and ND, reflecting differences in the collecting system used in the dredges (metallic grid vs net bag). When a net bag is used to retain the individuals, the mesh stretches while the dredge is being towed and prevents the escape of organisms through the mesh. The dredge therefore only becomes selective during the hauling process. When the metallic grid is used, selection of the captured individuals occurs throughout the tow. Gaspar *et al*. (2001) reported that the undamaged individuals that pass through the parallel rods of the GD grid burrow immediately (in the case of the infauna) or recover their activity (in the case of epifauna). This rapid reburying response decreases the probability of dislodged organisms being predated.

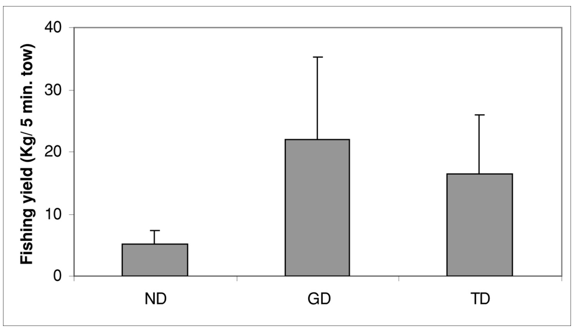


Figure 3. Standardised mean fishing yields (kg/5 min tow) obtained for the three dredges assayed. ND, north dredge; TD, traditional dredge; GD, grid dredge.

From our results it can be concluded that there are significant direct effects of dredging on some benthic species, as certain groups of animals suffer heavy damage while others are less affected. Studies have demonstrated consistently that there is an immediate effect on the density

Table 6. Percentage of damaged and dead individuals obtained per tow and dredge type.

| | Tow | | | | | | | | Mean | |
|---|---|---|---|---|---|---|---|---|---|---|
| | #1 | | #2 | | #3 | | #4 | | | |
| | Damaged (%) | Mortality (%) | Damaged (%) | Mortality (%) | Damaged (%) | Mortality (%) | Damaged (%) | Mortality (%) | Damaged (%) | Mortality (%) |
| North dredge | 36.35 | 26.79 | 19.51 | 11.64 | 18.30 | 13.26 | 30.44 | 21.47 | 26.15 | 18.29 |
| Grid dredge | 11.92 | 11.40 | 9.82 | 9.57 | 6.03 | 6.00 | 5.64 | 5.50 | 8.35 | 8.12 |
| Traditional dredge | 11.27 | 8.44 | 16.27 | 12.75 | 10.78 | 7.12 | 17.26 | 11.73 | 13.89 | 10.01 |

of both target and non-targeted organisms after the impact of mobile fishing gears. The short-term environmental effects of dredging on the sea floor have received increased attention in the last decade and several studies have detected changes in benthic communities due to dredging (e.g. Hall *et al*., 1990; Eleftheriou and Robertson, 1992; Kaiser and Spencer, 1996; Lambert and Goudreau, 1996; Bergman and van Santbrink, 2000). Short-term effects are therefore also expected in the Portuguese bivalve dredge fishery, but the question is whether or not this type of fishing causes long-term effects in the benthic community structure.

Biological communities that utilise a particular habitat have adapted to their environment through natural selection and the impact of mobile fishing gears on the habitat structure and biological community can be scaled against the magnitude and frequency of seabed disturbance due to natural causes (De Alteris *et al*., 1999). Although, for various species, mortality due to dredging appears to be fairly high, recolonisation can occur over a relatively short time period. Currie and Parry (1996), using a before-after-control-impact design experiment, reported the size and duration of scallop dredging impacts on soft sediment communities. The authors stated that reductions in density caused by dredging were usually small compared with annual changes in population density, where seasonal, and particularly inter-annual changes, were greater than those caused by dredging. Kaiser *et al*. (1998) found that immediately after fishing the composition of the community in stable sediments was significantly altered, while in mobile sediments the effects of fishing were not detectable. Nevertheless, after 6 months, seasonal changes had occurred in both communities and the effects of trawling disturbance were no longer evident. Similarly, Hall *et al*. (1990) found that despite the fact that suction dredging for *Ensis* sp. had profound immediate effects on benthic community structure, with consistent reduction in many macrofaunal species, after 40 days the abundance of species returned to pre-impact levels. By contrast, Pranovi and Giovanardi (1994) found that hydraulic dredging produced considerable long-term negative effects on the bottom environment of Venetian lagoon. These authors hypothesised that the slow recovery of the infaunal community was related to the medium/low energy conditions of the lagoon environment. Benthic communities inhabiting deeper waters may be less capable of sustaining and overcoming disturbance than benthic populations in shallow waters in more dynamic coarser sediments and accordingly have much longer recovery times (Jones, 1992).

Besides sediment type and conditions at a site, the severity of accumulated fishing effects also depends on the scale and intensity of the activity. If a large proportion of a fishing area is affected, then it is quite conceivable that the scope for movement by the associated benthos would be reduced and recovery would take longer (Hall, 1994; Thrush *et al*., 1995). Furthermore, although the effects of a single passage of a dredge gear may be relatively limited, chronic fishing disturbance may produce long-term changes in benthic communities (Sainsbury, 1988; Collie *et al*., 1997; Jennings and Kaiser, 1998; Bradshaw *et al*., 2000). Evidence nevertheless suggests that long-term changes in mobile sediments are probably restricted to long-lived fragile species (Eleftheriou and Robertson, 1992). Therefore, population reductions may only persist if the sediments in which they live are immobile (e.g. Kaiser, 1998; Ball *et al*., 2000) or that the affected area is large relative to the remainder of the habitat and a dilution effect cannot occur (Kaiser, 1998).

Thus, given the depth ($<35$ m) and the type of sediment (sandy bottoms) on which fishing is practised along the Portuguese coast and the relatively high natural disturbance found all year round, clam dredging is unlikely to have persistent effects on most infaunal communities. The effects on long-lived bivalve species could, however, be more serious. From this study, it was found that the ND damages and kills a higher proportion of macrofaunal individuals than the GD and TD. It was also found that for the same tow duration the ND mean fishing yield is significantly lower than those obtained with the GD and TD. Finally, our data showed that the GD is more selective than the other two dredges assayed. These results indicate that there are advantages in using the GD in the white clam fishery. Thus, in order to ban the use of the TD, fishermen of the small local dredge fleet should equip their boats with a small winch allowing for the use of the GD. The ND provokes a higher deleterious effect on the ecosystem than when the GD is used; therefore the ND should be banned from the fishery and replaced by the GD.

From a fisheries management and ecological points of view, our results clearly showed that there are obvious advantages in developing more efficient and selective dredges in order to reduce the number of damaged individuals and by-catch, and consequently decreasing the impact of dredging on macrobenthic communities.

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