Journal of the Marine Biological Association of the United Kingdom, 2019, 99(3), 575–585. © Marine Biological Association of the United Kingdom, 2018
doi:10.1017/S0025315418000462

Effects of mechanized dredging targeting *Chamelea gallina*, striped venus clams, on the associated discards in the northern Alboran Sea (Western Mediterranean Sea)

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Mechanized dredging impact on discards was assessed along the northern Alboran Sea (W Mediterranean Sea). Data from 101 dredging operations were analysed for contrasting spatial and seasonal variability of damage, with the use of a three-level damage scale. 4.5% of discarded individuals displayed intermediate damage, whereas 11.3% displayed severe damage. Echinoderms displayed the highest level of damage (~75% of total collected individuals) and Echinocardium cf. mediterraneum *was the most susceptible discarded species (85% with severe damage), followed by bivalves (7.3%) and crustaceans (3.3%). The target* Chamelea gallina *showed a low proportion of damaged individuals, probably due to their thick protective shell, which promotes the survival of discarded undersized target individuals. Spatial differences in damage level on discards were linked to some gear characteristics, to the higher amount of gravels and to longer tow durations, whereas damage was generally higher in cold months and partly related to higher quantities of hard shelled molluscs, in both cases increasing the abrasion and damage to retained organisms. Data suggest that dredges with a lower number of narrower iron teeth and towed for a shorter time could decrease the damage rate in discards of this fishery. A spatial management plan based on the type of grounds would be useful in order to improve efficiency of these fisheries and minimize their impact to soft bottoms with different commercial catches and biological communities.*

Keywords: Alboran Sea, artisanal fisheries, *Chamelea gallina*, damage, discards, dredging impact

Submitted 5 January 2018; accepted 7 June 2018; first published online 13 August 2018

INTRODUCTION

It is globally recognized that one of the most impactful human activities on the seabed is bottom trawling (Jennings & Kaiser, 1998; Agardy, 2000), which has increased in recent decades worldwide (Løkkeborg, 2005). The impacts of bottom trawling can be divided into (1) impacts on the seafloor and water mass environment, including scraping and ploughing of the seabed, sediment re-suspension, increasing water turbidity, alteration of seabed bathymetry and seabed flattening (Løkkeborg, 2005; Depestele *et al*., 2016); and (2) impacts on organisms, habitat-forming species and ecological processes, including direct damage to target and discarded species, changes in species composition, reduction of biomass, production and diversity, alteration of the functional diversity of communities, and modification of ecosystem functioning (Kaiser & Spencer, 1995; Bergmann *et al*., 2001; Hiddink *et al*., 2006; Tillin *et al*., 2006).

Physical impacts of fishing gears are variable and depend upon size and weight of the gear as well as fishing practice and behaviour. Bivalve dredges with teeth mounted along their width are used to target species that stay on the bottom or that are partly buried in the upper few centimetres of the sediment (Pérez Martín, 2003). Impacts on benthic communities caused by these gears have been widely documented (e.g. Currie & Parry, 1996; Pranovi *et al*., 2001; Leitão *et al*., 2014). Nevertheless, information regarding the impacts of certain fishing gears is still scarce due to the complexity and natural variability of benthic communities, as well as the difficulty related to conducting this type of study (Løkkeborg, 2005); the case of artisanal dredges operating at shallow bottoms in the western Mediterranean is an example (Urra *et al*., 2017).

One of the main target bivalve species in southern Europe is the venerid *Chamelea gallina* (Linnaeus, 1758), which is distributed throughout the Black and Mediterranean Seas and along the Algarve coast of southern Portugal, inhabiting preferentially coastal well-sorted fine sand biocoenoses (Pérès & Picard, 1964; Gaspar *et al*., 2004; Gofas *et al*., 2011). The artisanal fleet targeting this species in the Black Sea, along the Italian coast of the Adriatic Sea and in the Gulf of Cadiz (SW Spain), uses hydraulic blade dredges (Froglia, 1989; Dalgıç & Okumuş, 2006; Silva *et al*., 2014); whereas the fleet targeting it in the Alboran Sea and along the Algarve coast uses mechanized dredges (also called mechanical dredges)

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https://doi.org/10.1017/S0025315418000462 Published online by Cambridge University Press

(Gaspar *et al*., 2003a). Many studies have been carried out to analyse the rate of growth, life span, age/size at first maturity and gametogenic cycle of this species (Ramón & Richardson, 1992; Arneri *et al*., 1995; Rodríguez de la Rúa *et al*., 2003; Gaspar *et al*., 2004). Despite the importance of the *C. gallina* fishery, very few studies have analysed the discard composition and the damage sustained by both undersized commercial individuals and non-target species in this fishery (Moschino *et al*., 2003; Dalgıç *et al*., 2010; Dalgıç & Ceylan, 2012).

At present, a total of 247 boats are involved in the mechanized dredge fishery in the northern Alboran Sea, being part of a multi-target artisanal shellfish fleet. These boats vary in length from 7 to 11 m, with engines of an average ~35 Hp. The shellfish fleet targets mainly bivalves (e.g. wedge clam *D. trunculus*, striped venus clam *C. gallina*, smooth clam *Callista chione* and rough cockle *Acanthocardia tuberculata*), but it can focus its fishing effort on other target species (e.g. cephalopods) in certain seasons, which demand other gears. Mean total catches for *C. gallina* over the last 10 years are of ~24 (±4 SE) tons year^{-1}, and worth 172,000 (± 25,400) € year^{-1}, with a mean price of ~7.8 (±0.4) € kg^{-1} (http://www.juntadeandalucia.es). This fleet usually works with (i) dredges consisting of a rigid iron frame (~1 m length) with 40–50 round iron teeth (length: 10–15 cm; width: 8–10 mm) that rake the seabed and a plastic or metallic grid (mesh size: 17–20 mm) to hold the catch, and/or (ii) with dredges having a net bag (mesh size: 22 mm) and a lower number of iron teeth (~20) that are set further apart (up to 20 mm) (Baro *et al*., 1992). Each fishing operation takes about 30–40 min (including dredging at ~10 m min^{-1}, sorting and discarding), and is repeated several times in a circle around the 'gavilán' anchor (Figure 1). Marketable venus clams (>25 mm length) are retained and the rest, including undersized clams and non-target species (discards) are released to the sea.

Data regarding discard composition and discard rate for the mechanized dredging fishery of the southern Iberian Peninsula are scarce, and the information on the damage caused by these fishing gears on non-target species is very limited (Urra *et al*., 2017). This kind of information is crucial for the improvement of management of fisheries at an ecosystem level, as it is established in the EU Marine Strategy Framework Directive (2008/56/CE) and in the Common Fisheries Policy (EU Regulation No. 1380/2013), among other directives. This study analyses for the first time (i) the discards generated in the venus clam mechanized dredging fishery in the northern Alboran Sea (western Mediterranean), (ii) its seasonal and spatial variability, and (iii) its impact on the benthic and demersal fauna inhabiting the fishing grounds where the fleet operates in the northern Alboran Sea.

MATERIALS AND METHODS

Data collection

The discard composition/structure and the damage assessment were evaluated from discard samples collected at two fishing sites 29.7 nautical miles apart, Fuengirola and Caleta de Vélez (hereafter Caleta), along the northern margin of the Alboran Sea (Figure 2), as these areas represent very important fishing grounds for the artisanal fleet. Soft bottoms here are composed of terrigenous sediments with a dominance of fine sands and a high bioclastic (e.g. empty shells) content in Fuengirola, with mud content ranging between 2–21% and values for percentage of organic matter between 1–3%; whereas in Caleta, bottoms are composed of fine and medium sands, with higher values of both mud (2–77%) and organic matter content (1.6–4%) (García Raso *et al*., 2007; Sanz *et al*., 2007; Urra *et al*., 2011).

Samples were collected on board five similar commercial vessels ('El Lele', 'Hermanos Urda' and 'Nuevo Marielva' in Caleta; 'Nuevo Hermanos Madueño' and 'Nuevo Pelao' in Fuengirola) from 101 hauls carried out between March 2013 and March 2014. These were based on fishermen availability; N = 46 hauls for Caleta (spring: 15; summer: 15; autumn: 9; winter: 7), N = 55 hauls for Fuengirola (spring: 13; summer: 14; autumn: 9; winter: 19). Data regarding the fishing operation and the commercial catch were obtained onboard (catch was weighed (i.e. total wet weight) using hanging analogue scales). Normal fishing practices were adopted during the study. Overall, hauls were performed at a mean depth of 4.2 m and lasted 14.4 min, covering a mean area of 473.7 m^2. Random samples of a standardized weight of 5 kg were collected from the caught material and handled carefully, once the target individuals were separated by fishermen and before the non-commercial specimens were discarded at sea. Discard samples were then stored at −20°C until further processing in the laboratory, following the protocol used by Pranovi *et al.* (2000, 2001) for damage assessment to non-target species.

Once defrosted, inorganic (e.g. bioclasts, pebbles) and plant remains (e.g. seagrass, macroalgae) were separated from each sample and quantified, whereas individuals were handled carefully in order to avoid additional damage to the discarded specimens. Collected individuals were identified to species level (when possible) and quantified (abundance and biomass (±0.1 g wet weight)). Individual damage was assessed on a three-level scale depending on the morphology of the taxon (intact, intermediate and severe damage, as detailed in Table 1), and expressed in a standardized form for each species as percentage of individuals within each damage category (Bergmann *et al*., 2001). The experimental protocol considered the possibility of autotomy of arms and appendages by some echinoderms and crustaceans, respectively, as part of the fishing effects (e.g. physical damage, air exposure and acute temperature changes). Additionally, freezing/thawing can alter the body consistency, especially in crustaceans (i.e. loss of limbs) and echinoderms (i.e. loss of arms), therefore further loss of arms and appendages was expected. Nevertheless, a low amount of them were detected in the sorted samples. Scientific names for all taxa followed the nomenclature of the World Register of Marine Species (WoRMS) (http://www.marinespecies.org/).

Data analysis

Catch abundance, biomass and damage data were standardized to 15 min fishing operations (average hauling duration; N = 101). The abundance, weight, dominance (percentage of individuals/biomass of a species from the total catch) and frequency index values (percentage of samples in which a species is present) were calculated for every discarded species. The discard ratio of the fishery was calculated as σ discards/σ

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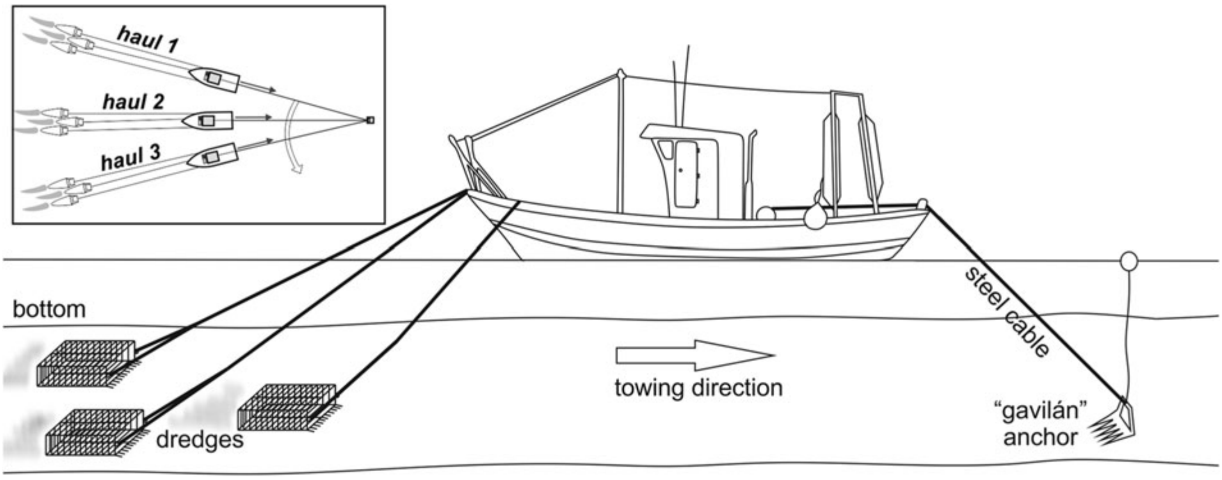

Fig. 1. Fishing technique using mechanized dredges targeting venus clam (*Chamelea gallina*) in the northern Alboran Sea. *Inset*: diagram of the fishing operation making concentric lines around the 'gavilán' anchor.

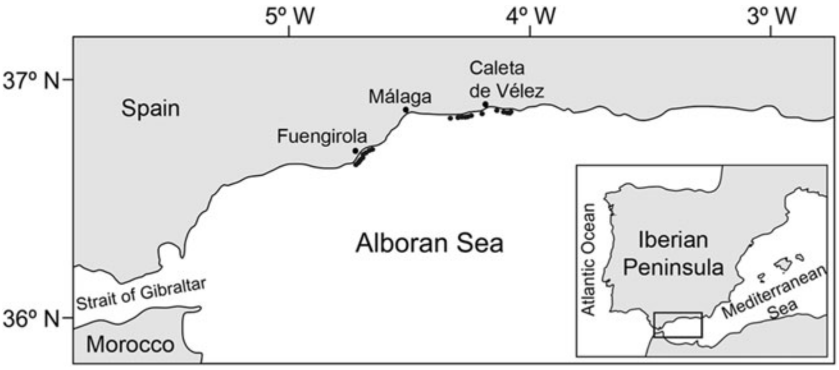

Fig. 2. Map of the study area in the northern Alboran Sea (western Mediterranean Sea), showing the location of the artisanal shellfish hauls analysed (black circles).

total catch (excluding debris). Comparisons between catch fractions and damage in different fishing grounds and seasons, as well as in frequently discarded species, were performed by means of one and two-factor analysis of variance (ANOVA). Transformation of data (i.e. arc-sine transformation for data expressed as percentages) was applied to satisfy the assumptions of parametric statistics (normality using Kolmogorov–Smirnov test, homoscedasticity using Levene test). Post hoc Tukey tests ($P < 0.05$) were used for a posteriori multiple comparisons.

The identification of similarities in the composition and structure of discards according to fishing ground was done using multivariate methods based on the Bray–Curtis similarity index. A fourth-root transformation pre-treatment was

Table 1. Criteria used for damage assessment of different taxa discarded in the northern Alboran Sea mechanized dredge fisheries targeting venus clams.

Taxon	Intermediate damage	Severe damage
Mollusca	Slightly cracked around the aperture (gastropods) or at the outer lip (bivalves)	Damaged apex (gastropods) or cracked beak/hinge (bivalves), or high level of fragmentation in shells
Asteroidea/Ophiuroidea	At least two undamaged arms and disc displaying no damage	No arms and/or crushed disc
Echinoidea	Weak damage in the exoskeleton or loss of some spines	Crushed or pinched exoskeleton or loss of most spines
Holoturoidea/Nemertea/Sipunculida	Body weakly scratched/damaged	Fragmented body or highly crushed
Decapoda	Presence of at least two pereopods at both sides and one chela	Less than two pereopods per side and/or no chelas, or with injured carapace
Annelida	Nearly all individuals are considered severely damaged since it was difficult to distinguish intermediate-severe damage due to different degree of body fragmentation	
Fishes	All individuals are considered severely damaged as their bodies were highly macerated or fragmented; besides the time they remained on the deck (~20 min)	

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applied on the quantitative (abundance, biomass) data in order to minimize the contribution of the most abundant species to the analysis (Clarke & Warwick, 2001). Distance-based permutational multivariate analysis of variance (PERMANOVA) was carried out on both biomass and abundance data to test for statistical differences in composition and structure between discards analysed in each site. The SIMPER procedure was used to identify those species that contributed most to the dissimilarity between discards.

The BIOENV procedure and distance based linear models (DistLM procedure) were used to test the linkage between damage (intermediate and severe data were pooled together) data and fishing (tow duration, trawled area, speed and depth), haul (amount of gravel in the catch, remains of shells, total wet weight (total catch + inert material)) and gear characteristics (number of iron teeth, length, width, distance among them, mesh size). Moreover, a Spearman rank correlation was run to test the relationship between damage data and fishing gear and haul characteristics. Univariate statistical analyses were performed using SPSS© statistical software, whereas multivariate analyses were executed using the software PRIMER6 and PERMANOVA+(Clarke & Warwick, 2001).

RESULTS

Discard analysis

Considering all components of the total collected material in the 101 hauls analysed, marketable venus clams represented 17.7% of the total weight, 47.2% corresponded to discards and 34.9% to debris (24.7% to dead shells, 8.9% to gravels and 1.3% to algae). The catch of the target *Chamelea gallina* (hereafter commercial catch) displayed an overall significant decreasing temporal pattern from spring (highest values) to winter (lowest values) (one-factor ANOVA: $F = 9.13$, $P < 0.005$), and the opposite trend (maxima in winter) was observed for the discarded biomass of both the target species and the total discard (one-factor ANOVA: *C. gallina* discard, $F = 7.78$; total discard, $F = 10.69$, in both cases $P < 0.005$). Significant spatial differences were observed for the mean commercial catch, being significantly higher in Caleta (one-factor ANOVA: $F = 5.63$, $P < 0.05$), and for the discarded fraction, with maxima in Fuengirola (one-factor ANOVA: $F = 30.2$, $P < 0.005$) (Table 2). The discard/total catch ratio (excluding debris) showed high fluctuations between hauls (minima: 0.1; maxima: 0.98), displaying significant spatial and temporal differences (two-factor ANOVA: factor site: $F = 17.9$, $P < 0.005$; factor season: $F = 3.2$, $P < 0.05$; interaction: $F = 0.85$, $P = 0.47$) with maxima in spring for Caleta (0.63 ± 0.03) and in winter for Fuengirola (0.91 ± 0.01).

Discards were composed of 96 taxa, with molluscs the best represented group with 53 species, followed by fish (17 spp.), decapods (12 spp.) and echinoderms (9 spp.). The number of species should be even higher because paguroid decapods and annelids could not be identified to species level. Taxa dominating discards in terms of biomass and abundance are indicated in Table 3. A large part of the fauna collected were filter feeders and deposit feeders (mainly bivalves), whereas about one third of the identified species correspond to carnivores and opportunistic scavengers (e.g. swimming crabs, hermit crabs, starfish, ophiurids, gastropods) of moribund

Table 2. Fishing characteristics and catch composition (mean biomass ± SE) recorded in 101 hauls analysed in the venus clam fishery with mechanized dredges of Fuengirola and Caleta de Vélez (northern Alboran Sea).

Hauls characteristics	**Fuengirola**				**Caleta de Vélez**			
Number of hauls analysed	55				46			
Trawled area (m²)*	422.2 (±22.9)				531.6 (±17.8)			
Depth (m)*	4.6 (±0.8)				3.7 (±0.1)			
Tow duration (min)*	12.0 (±0.4)				17.1 (±0.7)			
Speed (m min⁻¹)*	10.3 (±0.7)				11.3 (±3.7)			
Catch composition	**Mean (g haul⁻¹)**	***N***	**% Ni**	**% Ns**	**Mean (g haul⁻¹)**	***N***	**% Ni**	**% Ns**
Commercial catch	2214.8 (±232.9)				3666.9 (±1029.6)			
Discarded fraction								
Chamelea gallina (Target species)	1126.4 (±126.8)	20,553		0.4	468.6 (±102.4)	6409		2.5
Bivalves	6589.4 (±802.5)	43,098	0.0205	5.5	3783.5 (±959.5)	20,778	1.1	13.1
Gastropods	297.4 (±52.4)	12,495		0.2	70.0 (±22.0)	796	5.4	0.9
Cephalopods	0.7 (±0.5)	11		100				
Echinoderms	895.0 (±249.4)	11,690	28.9	46.4	161.0 (±26.6)	2791	51.3	27.5
Decapods	656.8 (±123.8)	29,147	1.3	2.6	142.0 (±61.4)	2751	11.1	4.8
Fish	19.8 (±6.3)	69		100	61.6 (±38.3)	86		100
Sipunculids	0.1 (±0.1)	3		100	0.1 (±0.1)	4		100
Anthozoans	0.5 (±0.5)	10		100				
Nemerteans	2.6 (±2.3)	24		100				
Total discards	9819.1 (±870.9)	96,542	1.5	10.2	5112.8 (±1153.4)	27,206	8.6	12.8
Debris								
Gravels	709.7 (±261.3)				2644.4 (±576.2)			
Bioclasts (shells)	4441.4 (±788.1)				4175.9 (±831.8)			

Information regarding the percentage of individuals with intermediate (%Ni) and severe (%Ns) damage for different faunistic groups is detailed. Proportions are given as percentages of the total number (N). Catch composition data are provided as standardized to 15 min haul duration. Analyses of variance (ANOVA) were carried out for testing spatial differences in the fishing characteristics. Significant differences ($P < 0.005$) are indicated with*.

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Table 3. Faunistic list of the top-25 dominant macrobenthic organisms in discards of the venus clam fishery in Fuengirola and Caleta de Vélez (northern Alboran Sea).

	Fuengirola				**Caleta de Vélez**			
Taxa	**N**	**B**	**% F**	**% Ns**	**N**	**B**	**% F**	**% Ns**
Acanthocardia tuberculata[1]	106.9 (±10.9)	4946.4 (±622.)	100	3.4	75.6 (±17.6)	2206.1 (±449.4)	97.8	7.9
Mactra stultorum[1]	69.7 (±7.4)	554.6 (±86.5)	96. 4	35.6	126.9 (±48.1)	1181.3 (±386.7)	93.5	34.1
Chamelea gallina[1]	369.6 (±47.2)	1126.3 (±126.8)	98.2	0.9	135.1 (±28.2)	468.6 (±93.7)	100	9.5
Echinocardium cf. *mediterraneum*[4]	177.5 (±65.4)	738.7 (±244.4)	76.4	83.6	1.2 (±0.4)	7.3 (±2.7)	26.1	89.6
Paguroidea[3]	513.6 (±99.5)	620.6 (±121.2)	94.5	0	45.9 (±16.5)	94.1 (±41.3)	89.1	0
Glycymeris nummaria[1]	21.5 (±2.8)	431.9 (±85.9)	94.5	1.3	5.7 (±1.9)	161.2 (±74.9)	47.8	7.3
Callista chione[1]	22.4 (±3.4)	287.9 (±58.3)	92.7	1.9	1.1 (±0.6)	54.4 (±44.1)	26.1	11.1
Tritia reticulata[2]	204.4 (±36.9)	279.7 (±51.3)	87.3	0	9.9 (±2.7)	16.5 (±4.3)	52.2	0
Spisula subtruncata[1]	105.1 (±12.2)	210.1 (±25.3)	98. 2	0.2	41.3 (±11.2)	84.8 (±21.5)	71.7	3.4
Astropecten irregularis[6]	5.5 (±1.1)	58.8 (±14.2)	52.7	25.1	5.2 (±2.2)	39.6 (±12.3)	52.2	8.5
Ophiura ophiura[5]	24.3 (±3.7)	36.9 (±6.3)	89. 1	17.5	45.2 (±10.9)	49.9 (±11.9)	78.3	19.1
Donax venustus[1]	34.6 (±7.2)	59.1 (±12.4)	69.1	0.7	2.5 (±1.2)	4.7 (±2.3)	26.1	0
Luidia atlantidea[6]	1.7 (±0.5)	43.6 (±11.3)	30.9	91.2	0.8 (±0.4)	20.0 (±7.3)	21.7	80
Astropecten aranciacus[6]	0.6 (±0.2)	14.2 (±5.5)	14.5	0	0.9 (±0.3)	40.2 (±16.1)	21.7	31.8
Liocarcinus vernalis[3]	9.4 (±1.6)	19.9 (±4.6)	69. 1	45.5	4.0 (±2.9)	17.3 (±13.6)	32.6	61.3
Dosinia lupinus[1]	4.1 (±0.9)	12.9 (±3.2)	52.7	2.5	7.2 (±2.3)	24.5 (±7.4)	65.2	6.5
Laevicardium crassum[1]	2.3 (±0.5)	31.8 (±6.1)	45.4	2	0.07 (±0.05)	1.1 (±0.7)	4.3	0
Ophichthus rufus[7]	0.02 (±0.02)	1.6 (±1.6)	1.8	100	0.3 (±0.3)	32.07 (±29.3)	2.2	100
Polychaetes[8]		19.6 (±9.2)	45.4	20		1.4 (±0.7)	23.9	0
Mactra glauca[1]	0.4 (±0.3)	1.9 (±1.2)	7.3	0	1.5 (±0.9)	24.3 (±16.6)	8.7	39.2
Cymbium olla[2]	0.06 (±0.06)	0.2 (±0.1)	1.8	100	1.2 (±1.1)	24.7 (±19.3)	4.3	0
Albunea carabus[3]	0.3 (±0.1)	2.1 (±1.1)	7.3	33.3	4.1 (±3.3)	20.1 (±14.3)	23.9	15.1
Ensis minor[1]	2.4 (±0.5)	8.1 (±2.2)	32.7	89. 2	3.8 (±3.3)	10.4 (±8.2)	15.2	90.5
Atelecyclus undecimdentatus[3]	1.04 (±0.3)	9.2 (±2.9)	27. 3	40.6	0.8 (±0.5)	8.7 (±4.8)	6.5	7.4
Bivetiella cancellata[2]	1.1 (±0.4)	4.6 (±1.6)	23.6	0	2.6 (±0.7)	13.9 (±3.4)	43.5	5

Mean abundance (N; ind·haul^{-1}) and biomass (B; g·haul^{-1}) (± standard error), as well as frequency index value (%F; percentage of samples in which a species is present) and percentage of individuals with severe damage (%Ns; proportions are given as percentages of the total number), are indicated for each taxa and site. Species belong to the following taxonomic groups: [1]Class Bivalvia (Mollusca); [2]Class Gastropoda (Mollusca); [3]Order Decapoda (Crustacea); [4]Class Echinoidea (Echinodermata); [5]Class Ophiuroidea (Echinodermata); [6]Class Asteroidea (Echinodermata); [7]Class Actinopterygii (Chordata); [8]Class Polychaeta (Annelida).

discarded benthic fauna. In terms of biomass, infaunal bivalves dominated (~78% total biomass in Fuengirola; ~90% in Caleta), and the pattern was similar for the abundance, with a higher fraction of other faunistic groups in Fuengirola than in Caleta (Figure 3, Table 2). In fact, PERMANOVA revealed significant spatial differences in the discarded biomass (Pseudo-$F = 16.1$; $P < 0.001$) and abundance (Pseudo-$F = 16.9$; $P < 0.001$) among fishing grounds, with a higher discard for most quantitatively dominant taxa in Fuengirola according to SIMPER (average dissimilarity >52%). Overall, the mean biomass of discard caught per 500 g of target species (60 ind.) was 1334.3 g and includes 923.4 g of bivalves (106 ind.), 97.5 g of echinoderms (24 ind.), 73.4 g of decapods (54 ind.) and 33.7 g of gastropods (22 ind.), among other taxa.

Damage assessment

The damage assessment for all species showed that 84.2% (±1.4) were undamaged individuals, 4.5% (±0.7) were individuals displaying intermediate damage and 11.3% (±1.1) displayed severe damage. The intermediate damage level was significantly higher in Caleta than in Fuengirola (two-factor ANOVA: factor site: $F = 36.2$, $P < 0.001$; factor season: $F = 0.9$, $P = 0.43$; interaction: $F = 2.9$, $P < 0.05$), and the pattern was similar for severely damaged individuals (two-factor ANOVA: factor site: $F = 15.6$, $P < 0.001$; factor season: $F = 1.9$, $P = 0.13$; interaction: $F = 1.5$, $P = 0.21$) (Table 2). The highest proportions of damaged individuals were observed in winter and spring in both Caleta and Fuengirola (Figure 4).

The analysed fishing, haul and gear characteristics displayed a low but significant correlation with individuals that had some sort of damage (intermediate and severe pooled together; hereafter total damage) (BIOENV: $\rho = 0.36$, $P < 0.005$). The best combination of variables through this correlation was, according to BIOENV analysis, amount of gravel–number of iron teeth–iron teeth width, whereas DistLM marginal tests also assigned some of the variation to tow duration and iron teeth length ($P < 0.05$). Significant but very low positive correlations were found between the proportion of damaged individuals and tow duration ($R_S = 0.39$, $P < 0.001$), number of iron teeth ($R_S = 0.33$, $P < 0.001$) and length of iron teeth ($R_S = 0.29$, $P < 0.005$), whereas a significant negative correlation was found between the proportion of damaged individuals and width of iron teeth ($R_S = -0.55$, $P < 0.001$). Figure 5 shows the distribution of analysed samples with damage data in relation to the analysed fishing, haul and gear characteristics, reflecting spatial differences in the level of damage caused to discards.

Echinoderms showed the highest level of total damage within discards in both sites, with proportions of severely damaged individuals significantly higher in Fuengirola (Table 2; one-factor ANOVA: $F = 5.6$, $P < 0.05$). Crustaceans

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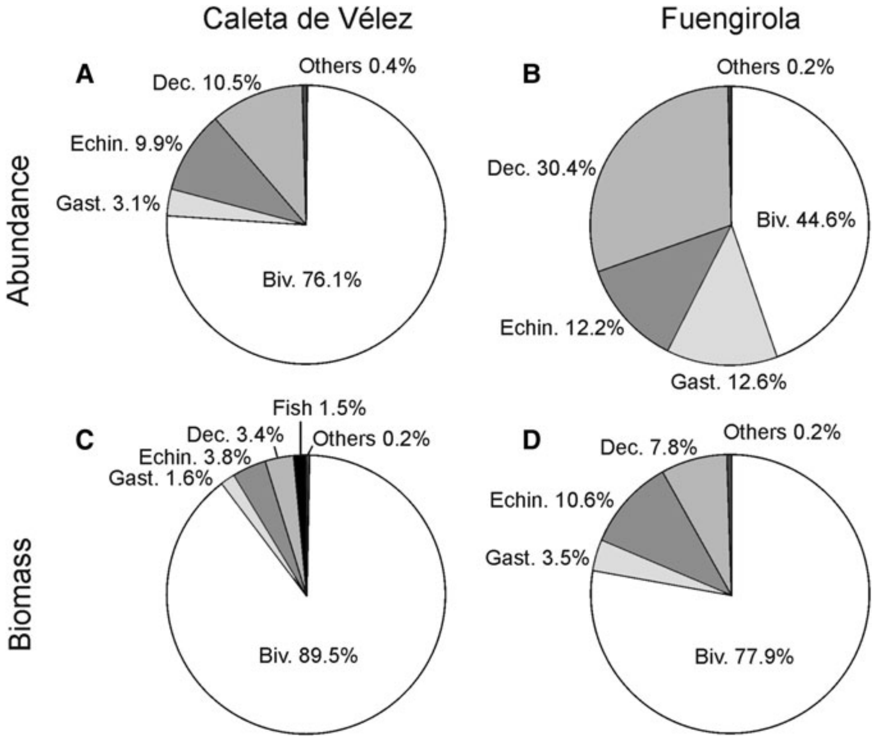

Fig. 3. Relative composition of discards in the venus clam fishery in Caleta de Vélez (A, C) and Fuengirola (B, D) (northern Alboran Sea). Biv., bivalves; Gast., gastropods; Echin., echinoderms; Dec., decapods.

and bivalves also displayed high levels of intermediate and severe damage, respectively, in both sites (Table 2), with significantly higher proportions of damaged individuals in Caleta (one-factor ANOVA: crustaceans with intermediate damage, $F = 7.8$; bivalves with severe damage, $F = 30.1$, $P < 0.005$ in all cases). Some taxa with minor catch (cephalopods, cnidarians, nemerteans, fish, sipunculids and polychaetes) also showed high levels of damage (e.g. 100% damage for fish due to the high degree of maceration and/or fragmentation of their bodies), but they represented less than 1.5% of total damaged individuals. The observed pattern was similar regarding biomass, with echinoderms showing damage to

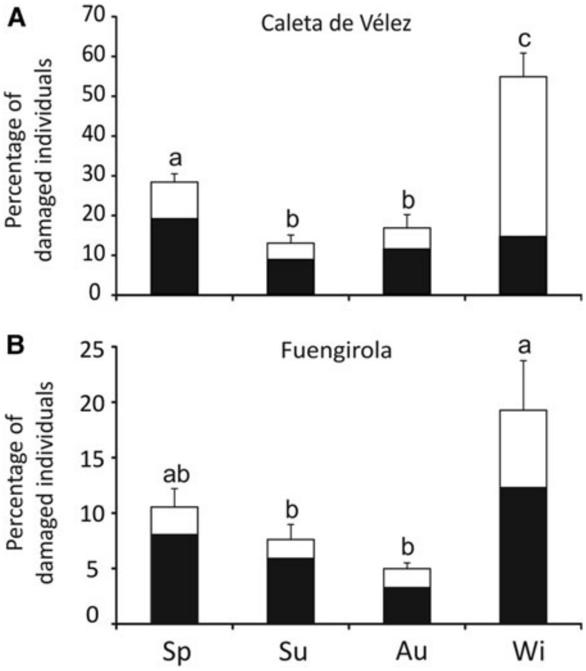

Fig. 4. Proportion of damaged individuals (% ind. haul^{-1}) in discards of the venus clam fishery of Caleta de Vélez (A) and Fuengirola (B) (northern Alboran Sea). Shaded areas of bars indicate proportion with severe damage and empty areas indicate proportion with intermediate damage. Error bars represent standard error. Lower case letters above error bars display the results of post-hoc test; different letters distinguish significantly different means at $P < 0.05$. Sp, spring; Su, summer; Au, autumn; Wi, winter.

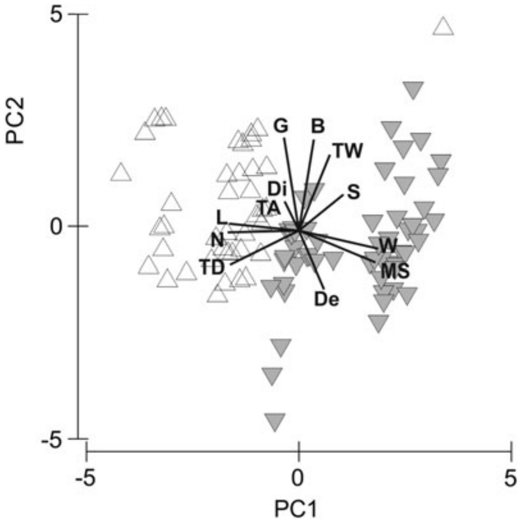

Fig. 5. Two-dimensional biplot showing the relationship of total damage data and environmental variables including fishing (TD, tow duration; TA, trawled area; S, speed; De, depth), haul (G, amount of gravel in the catch; B, remains of shells or bioclasts; TW, total wet weight (total catch + debris)) and gear characteristics (N, number of iron teeth; L, length; W, width; Di, distance among them; MS, mesh size).

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75.2% of their biomass. In contrast, none of the paguroids and <1% of gastropods were severely damaged.

Damage among the most abundant and/or frequently caught species was highly variable (Figure 6; Table 3). Regarding severe damage, the echinoid *Echinocardium* cf. *mediterraneum* (Forbes, 1844) was the most susceptible species with 84.9% of individuals displaying crushed exoskeletons. The decapod *Liocarcinus vernalis* (Risso, 1827) showed ~50% of individuals with crushed carapace and/or the loss of both chelae and many pereiopods, whereas the bivalve *Mactra stultorum* (Linnaeus, 1758) showed 34.9% of individuals with crushed valves or fatal chipping at the outer margin of the shell or even hinge displacement. Other echinoderms such as *Ophiura ophiura* (Linnaeus, 1758) and *Astropecten irregularis* (Pennant, 1777) showed ~18% of severely damaged individuals, with loss of all arms and/or damage to the disc. The target species *C. gallina* showed a low proportion of damaged individuals (4.9% ind.), probably due to their thick protective shell as also observed for other bivalves such as *Callista chione* (Linnaeus, 1758) and *Glycymeris glycymeris* (Linnaeus, 1758) (~3% ind.). Percentages of severely damaged individuals were generally higher in Caleta, with significantly higher values for abundant species including *C. gallina*, the bivalves *Acanthocardia tuberculata* (Linnaeus, 1758) and *G. glycymeris*, and *E.* cf. *mediterraneum* (Figure 6; Table 4). Regarding seasons, few of them showed significant seasonal differences in the proportion of severely damaged individuals, including *C. gallina* that showed the maxima in spring in both sites, and the bivalve *Glycymeris nummaria* (Linnaeus, 1758) and *O. ophiura* that showed maxima in autumn-winter (Table 4).

DISCUSSION

This study provides the first complete assessment of the discards associated with the mechanized dredging fleet targeting venus clam (*Chamelea gallina*) in the western Mediterranean Sea, where the information regarding discards of this type of fisheries is very limited (Urra *et al*., 2017). The analysis of discards could provide a baseline for fisheries assessment, but also a useful tool for monitoring benthic biodiversity components such as native and exotic range-expanding species in this area where some marine protected areas have been recently declared for the benthic biodiversity conservation (e.g. Calahonda) (Urra *et al*., 2015).

Our results suggest a poorly selective fishery, with the collection of more than double the biomass of discarded species than target species (~73% of total catch excluding debris). This would confirm that new more selective fishing gears should be developed in order to reduce high discard values, prompting further field experiments on the selectivity of traditional dredges towards improving their efficiency. Similarly, high percentages of discards are commonly reported in fisheries targeting bivalves in European coastal waters, such as in 'Rapido' trawling for scallops (Pranovi *et al*., 2001), in hydraulic dredging for venus clams (Morello *et al*., 2005), or in hydraulic blade dredging for razor clams (Hauton *et al*., 2003). Regarding this, Gaspar *et al*. (1999) concluded that tooth spacing did not have an effect on the selectivity of clam dredges of the southern Portuguese artisanal fleet, whereas an appropriate mesh size will result in a considerable reduction in the numbers of small- and medium-sized individuals in the catch.

Spatial differences observed for the commercial catch and the discarded fraction could be related to (i) the different sedimentary characteristics of the two fishing sites, which would determine differences in the composition and structure of the benthic community as reflected by the multivariate analyses, (ii) the patchy spatial distribution of the target species, and (iii) some minor different gear characteristics due to the artisanal character of this fishery. Hall-Spencer *et al*. (1999) and Pranovi *et al*. (2001) reported high discard/commercial ratios in areas with high densities of non-target species for the Rapido trawling fisheries in the northern Adriatic Sea; and Gaspar *et al*. (2001) reported by-catch proportions of 25–48% in the Portuguese smooth clam fishery due to differences in gear specifications and structure and composition of benthic communities. Results provided here suggest that a spatial management plan based on the type of grounds being fished would be useful in order to improve efficiency of these fisheries and minimize their impact in soft bottoms with different commercial catches and biological communities.

Data collected in this study would suggest that mechanized dredges with a lower number of narrower iron teeth, and towed for a shorter time, would decrease the damage rate in discards of this fishery. Nevertheless, further experimental hauls should be undertaken in order to confirm if the

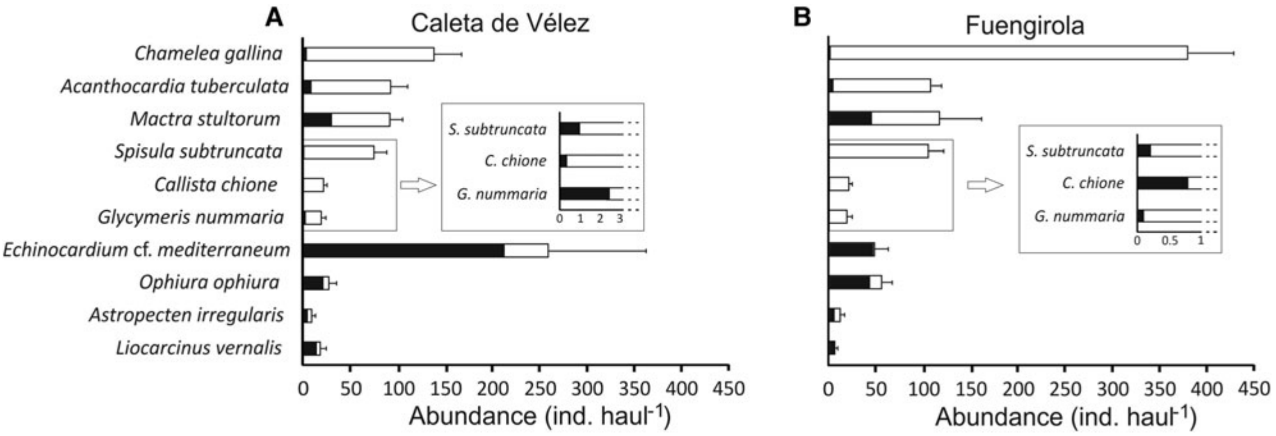

Fig. 6. Mean abundance of the most representative discarded species in the venus clam fishery of Caleta de Vélez (A) and Fuengirola (B) (northern Alboran Sea). Shaded areas of bars indicate proportion of individuals with any damage (intermediate and severe pooled together). Mean + standard error.

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Table 4. Results of two-factor ANOVA analyses for testing differences in the proportion of damaged individuals of frequent discarded species in relation to site and season in the northern Alboran Sea mechanized dredge fisheries targeting venus clams.

Source of variation	*n*	df	SS	MS	*F*	*P*
Acanthocardia tuberculata	101					
Site		1	0.047	0.047	10.867	<0.001
Season		3	0.026	0.009	1.969	0.124
Site × Season		3	0.028	0.009	2.126	0.102
Chamelea gallina	101					
Site		1	0.607	0.607	23.606	<0.001
Season		3	0.682	0.227	8.835	<0.001
Site × Season		3	0.618	0.206	8.004	<0.001
Glycymeris nummaria	101					
Site		1	0.358	0.358	15.648	<0.001
Season		3	0.693	0.231	10.117	<0.001
Site × Season		3	0.523	0.174	7.623	<0.001
Echinocardium cf. *mediterraneum*	101					
Site		1	5.662	5.662	14.491	<0.001
Season		3	0.257	0.086	0.219	0.883
Site × Season		3	4.053	1.351	3.458	<0.05
Ophiura phiura	101					
Site		1	0.014	0.014	0.119	0.731
Season		3	1.369	0.456	3.912	<0.05
Site × Season		3	0.650	0.217	1.859	0.142
Liocarcinum vernalis	101					
Site		1	0.151	0.151	0.567	0.453
Season		3	2.741	0.914	3.430	<0.05
Site × Season		3	2.772	0.924	3.469	<0.05

decreased damage rate is observed in other independent studies. Moreover, the amount of gravels in the catch was also selected as a variable explaining some of the variation in damage data, therefore becoming a factor to be considered when selecting areas for fishing regarding the type of community inhabiting that ground. Many authors have reported that damage to benthic organisms is dependent on several factors acting together, including vessel, fishing gear and haul characteristics, which can differ according to depth and habitat type (Gaspar *et al.*, 1998, 2002, 2003a; Bergmann *et al.*, 2001; Pranovi *et al.*, 2001), as well as on-deck sorting procedures (Pranovi *et al.*, 2001). Moreover, damage to benthic organisms is higher when fishing gears are towed on rocky, muddy or detritic bottoms because the net fills with different materials that considerably damage the catch during towing, hauling and sorting operations (Jennings & Kaiser, 1998; Pranovi *et al.*, 2001), as perceived in the multivariate analyses of this study. Therefore, the impact of even small artisanal dredges on benthic communities is real but complex and difficult to assess, with a detailed analysis of each fishery being necessary towards understanding the extent of damage sustained by organisms.

Damage was generally higher in winter but the reasons for this are difficult to identify and are probably linked to a combination of factors associated with the catching and sorting process. According to the analysed data, this could be related to the higher amounts of discards in this season, mainly of hard shelled molluscs which accounted for ~75% of the total catch, including undersized target individuals. This hard material promotes the abrasion between organisms with weak exoskeletons (e.g. irregular echinoids, ophiuroids) and those with hard shells and with debris inside the metallic grid during towing and hauling (Pranovi *et al.*, 2001; Broadhurst *et al.*, 2006). Other factors to be considered are the higher fragility of certain species during their moulting periods, for example of decapods (Raviv *et al.*, 2008), that makes them more susceptible to damage from fishing activities, or the bathymetric migrations linked to reproductive strategies. Moreover, discarded organisms are also subject to additional cumulative stress linked with being brought to the surface, exposed to air for sorting activities and thrown from the vessel (Broadhurst *et al.*, 2006), which should be monitored in future studies to decrease potential negative effects. Furthermore, other potential factors would be related to the lower catch of the target species in cold months, together with the higher catch of discards, which would involve a higher number of fishing operations to get the daily catch. In this respect, the artisanal fleet concentrates its fishing effort in a narrow stretch of coastline, and thus the probability of capturing and damaging previously injured organisms is high.

Overall ~84% of total individuals collected were undamaged but every faunistic group displayed some sort of damage in the discards of this fishery, with echinoderms generally displaying the highest level of damage. Several authors have reported on the fragility of echinoids as an impact of fishing activities, linking their brittle and vulnerable exoskeletons with their high mortality (Hall-Spencer *et al.*, 1999; Pranovi *et al.*, 2001). The echinoids *Echinocardium* spp. live buried in sandy sediments and move at a maximum speed of 6–8 cm per hour (Schultz, 2006), so mechanized dredges can collect many individuals of these species that are generally damaged due to rubbing and crushing with the collected hard material. A high percentage of collected asteroid, and especially ophiurid individuals, presented missing arms and arms that were regenerating, probably associated with previous fishing impacts (Gallardo-Roldán *et al.*, 2015). Ophiuroids have been reported to be more susceptible to damage than asteroids, with higher mortality rates due to their fragile exoskeleton (Kaiser & Spencer, 1995; Bergmann *et al.*, 2001); although both groups have a high regenerative capacity (Candia Carnevali, 2006).

The loss of a chela or few pereiopods (many times with breaks extending into the body) was frequently observed in all decapod species, as well as crushed carapaces, which represent a major cause of death (Juanes & Smith, 1995; Bergmann & Moore, 2001; Bergmann *et al.*, 2001). This is of importance because several authors have reported that the consequences of non-lethal injuries can increase the long-term mortality in discarded live damaged crustaceans (Smith & Hines, 1991; Juanes & Smith, 1995; Hall-Spencer *et al.*, 1999; Bergmann & Moore, 2001), especially in particularly vulnerable species such as the abundant *L. vernalis*. In contrast, almost all hermit crabs were in perfect condition due to the protection provided by gastropod shells. These organisms are important scavengers that can consume large amounts of discards, enhanced by their ability to quickly migrate and aggregate in recently trawled areas (Ramsay *et al.*, 1996). This could partly explain why hermit crabs are among the most abundant taxa in total catches in areas that are frequently dredged such as those studied in the northern Alboran Sea.

Bivalves were much more susceptible to damage than gastropods, the latter being generally undamaged as a result of

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their strong shells and, in some cases, smaller sizes. Nevertheless, larger species (e.g. *Cymbiun olla*) showed some chipping of the outer lip, whereas some bivalve species characterized by relatively thin shells (e.g. *M. stultorum*, *Pharus legumen*, *Ensis ensis* and *E. minor*), displayed a high percentage of damaged individuals, as observed in other shallow dredging fisheries (Hall-Spencer *et al*., 1999; Pranovi *et al*., 2001; Gaspar *et al*., 2003b). In contrast, thick-shelled bivalves are more resistant to fishing (Bergmann *et al*., 2001; Gaspar *et al*., 2003b), as detected for the target species *C. gallina* or other commercial bivalves (e.g. *C. chione*), of which $<5\%$ of total individuals presented severe damage. This is of importance for commercial species (but also for non-commercial species) because it promotes the survival of discarded undersized target individuals, contributing to the sustainable exploitation of the resource.

In summary, mechanized dredging targeting venus clams in the northern Alboran Sea can cause considerable damage to some benthic and demersal species and groups in particular, but only corresponds to 15.8% of the total individuals collected in discards. The level and type of damage observed is dependent on species-specific characteristics such as morphology, body size and structure, and the extent of this damage is influenced by fishing gear and haul characteristics. Experimental hauls with modified mechanical dredges on different soft bottom types should be undertaken in order to investigate how to minimize their ecological impact. Considering the low proportion of damaged individuals observed in discards of this fishery, and that discards are released on suitable sedimentary habitats soon after on-deck sorting, a high potential survival rate for many organisms could be expected (Broadhurst *et al*., 2006). This would further support the temporary derogation of the landed obligation that has recently been granted for certain fisheries in the Mediterranean Sea, including those targeting bivalves (mentioned as *Venus* spp. in the EU documents). Nevertheless and despite an apparent good condition for many discarded benthic invertebrates, long-term mortality of discards is likely to occur due to sub-lethal damage, internal injuries and physiological stress, as observed in different studies and experiments (Kaiser & Spencer, 1995; Gaspar & Monteiro, 1999; Bergmann & Moore, 2001; Pranovi *et al*., 2001). Therefore, a low proportion of damaged individuals would not necessarily imply a high survival, and post-trawling mortality of discarded organisms may have been underestimated in the past (e.g. for crustaceans: Bergmann & Moore, 2001). Despite this, benthic communities inhabiting shallow and dynamic environments with soft sediments have shown a greater capacity to recover from fishing disturbance (Jones, 1992; Currie & Parry, 1996; Kaiser *et al*., 1998), and could also benefit from the high local productivity of the northern Alboran Sea (Sarhan *et al*., 2000), which could decrease the long-term impact of this artisanal dredging fishery on soft bottoms of the Alboran Sea.

ACKNOWLEDGEMENTS

We thank the captains and crew of the commercial vessels who have collaborated with the REMARAN team; to Ana Garrido, Alejandro J. Ibañez Yuste and Alejando Terrón Sigler (AGAPA-Junta de Andalucía) for the collection of faunistic samples and continuous interest; to Alba Rojas García, Blanca Orúe Montaner and Marina Gallardo Núñez for their help in processing the samples; to José Miguel Serna (Centro Oceanográfico de Málaga) for his help with the GIS facilities, and other members of the research team for their collaboration.

FINANCIAL SUPPORT

This study was developed under the collaboration agreement between Junta de Andalucía (Spain) and Instituto Español de Oceanografía (IEO) (Contract 126/2012-SEN), within the framework of the research project entitled 'Estudio integral en zonas de protección pesquera y marisquera y otras áreas marinas protegidas del litoral andaluz: Estudio previo para la protección, ordenación y determinación de reservas marisqueras en el litoral mediterráneo de Andalucía' (REMAN-REMARAN). This project was funded by the European Fisheries Fund.

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https://doi.org/10.1017/S0025315418000462 Published online by Cambridge University Press