Biodiversity assessment and geographical affinities of discards in clam fisheries in the Atlantic–Mediterranean transition (northern Alboran Sea)

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Abstract

This study focused on the assessment and quantification of discards generated by clam fisheries along the northern Alboran Sea (western Mediterranean). Discard samples (n= 278) were collected throughout one year on board nine commercial vessels. A total of 129 species were identified, mostly represented by molluscs (72 spp.), arthropods (20 spp.) and echinoderms (12 spp.). Molluscs dominated in terms of abundance (67.5%) and biomass (94.2%). The superfamily Paguroidea (i.e. hermit crabs), together with undersized target individuals, were the most abundant taxa. The abundance and biomass of discards displayed significant maximum values in winter, which could be partly related to biotic factors including population dynamics of some dominant species. Multivariate analyses indicated the presence of different assemblages related to the targeted bivalve species, reflecting the transition between a fine surface-sands biocoenosis exposed to wave action and a well-sorted fine sands biocoenosis below 5 m depth. Analysis of biogeographical affinities showed that most discarded species (73.2%) have an extensive Atlantic range, whereas 7.1% have a restricted distribution within the Mediterranean. The presence of subtropical species highlights the uniqueness of this area (the Atlantic–Mediterranean transition) in European seas. The usefulness of discard analysis for biodiversity assessment is discussed.

Running title: Discards in clam fisheries in the Atlantic–Mediterranean transition

Keywords: Alboran Sea, artisanal fisheries, biological diversity, biogeographical affinities, discards, mollusc

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Conflicts of Interest Statement

The authors certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, etc.), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Introduction

The Alboran Sea represents the westernmost region within the Mediterranean, being located between Spain, Morocco and Algeria. Its small and narrow basin has a distance of about 350 km from the Strait of Gibraltar to the line between Cape of Gata (Almeria, Spain) and Cape Fegalo (Oran, Algeria), which defines a delineation of ecological processes according to seasonal oceanographic conditions (Parrilla & Kinder 1987). The Alboran basin stands out for different reasons: (1) there is an exchange of water masses between the Atlantic and the Mediterranean through the Strait of Gibraltar, with Atlantic water flowing in at the surface and saltier Mediterranean water flowing out close to the bottom (Lacombe & Tchernia 1972; Lanoix 1974; Hopkins 1978); (2) the physiography of this basin, with a narrow continental shelf (generally between 5-8 km) and the shelf break at 100-150 m depth, and the presence of submarine canyons, seamounts and other kind of sea floor elevations, has a great influence on the distribution of water bodies and their circulation (Ercilla et al. 2016 and references therein); (3) the presence of nutrient-rich upwelling waters and other hydrological conditions generate a higher planktonic productivity than in other Mediterranean regions (Minas et al. 1991; Sarhan et al. 2000); and (4) it represents the confluence point of three biogeographical units (Lusitanian, Mauritanian and Mediterranean) and, therefore, the confluence of organisms from those areas (Ekman 1953; Bianchi & Morri 2000; Templado 2011; Rueda et al. accepted). For all these, the Alboran Sea stands out within the Mediterranean and European contexts due to its great ecological importance and biogeographic singularity.

As a result of the particular geomorphological and hydrodynamic characteristics of the Alboran Sea, the biological diversity and of ecosystems existing here is recognized as one of the greatest for the Mediterranean basin (García Raso et al. 2010; Templado 2011; Rueda et al. accepted). This high biodiversity includes many commercially important species for fisheries, both benthic (e.g. sea anemone, clams, octopus), demersal (e.g. European hake, small sharks, sparids) and pelagic (e.g. anchovy, sardine, tunas) (Pérez & Rodríguez 2001), which are supported by this high productivity. An important fishing industry exists in the northern Alboran basin as a consequence of this rich abundance of biological resources, being artisanal fisheries the best represented for the practice of the fishing activity. Artisanal fisheries (i.e. vessels up to ca. 11 m in length, performing daily fishing trips close to the coast and mostly using selective fishing gears) in the northern Alboran Sea include mainly those using mechanical dredges

(dredges hereafter) to catch bivalves, traps and pots to catch octopus and trammel nets to catch fishes (Baro et al. accepted). Of these, clam fisheries using dredges represent 61% of the artisanal fleet, and are characterized by the volume, prize and high quality of their catches (http://www.juntadeandalucia.es/agriculturaypesca/idapes/). The fleet targets mainly bivalves, being the wedge clam (*Donax trunculus*), the striped venus clam (*Chamelea gallina*) and the smooth clam (*Callista chione*) the species with the highest values of catch volume and market prices for this area, together with the rough cockle (*Acanthocardia tuberculata*), which is caught punctually on certain years at the request of the local canning industry. Nevertheless, this fleet can focus its fishing effort on other target species (e.g. cephalopods, fishes) in certain seasons, which demands other gears.

Fishing is one of the activities that has historically been most regulated, both in terms of methods and techniques of extraction, as in the marketing and presentation of products, and clam fisheries are not an exception. Currently, the extraction of littoral benthic resources in Spanish waters is subjected to diverse European and Spanish directives such as the Regulation (EU) No 1380/2013 on the Common Fisheries Policy (CFP), the Council Regulation (EC) No 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, the Council Decision (EC) No 98/4106 on the accession of the European Community to the General Fisheries Commission for the Mediterranean, and the Order AAA/2808/2012 of the Spanish Government establishing an Integrated Management Plan for the conservation of fishery resources in the Mediterranean affected by fisheries using purse seine nets, trawl nets and fixed and small gears. One of the main objectives of the CFP is to establish a scientific basis for fisheries management, where Member States will collect the biological, environmental, technical and socio-economic data necessary for ecosystem-based fisheries management. In this line, data regarding discard composition (i.e. the portion of the total catch brought on board and then returned to the sea for whatever reason) is considered of importance for fisheries management, allowing to improve the knowledge on the composition of benthic communities harbouring living resources that are included in several European Directives such as the Directive 2008/56/EC (Marine Strategy Framework Directive) and the CFP. Besides, it provides a baseline for biodiversity conservation purposes, with the monitoring of rare and singular species. This is of interest in the Alboran Sea as it represents a biodiversity hotspot in an Atlantic-Mediterranean marine transition area, where some marine protected areas have been recently declared for the benthic biodiversity conservation (Urra et al. 2015).

This work aimed to analyze (1) the composition and structure of discards generated by the mechanical dredge fishery for clams in the northern Alboran Sea, and (2) the biogeographical affinity of the collected fauna using discard samples collected on-board commercial vessels. It also aimed to provide a baseline to evaluate potential changes in soft bottom communities inhabiting the northern coast of the Alboran Sea and to implement future conservation strategies.

Material & Methods

Study area

The study area comprised infralittoral fishing grounds (generally between 1 and 30 m depth) around the commercial fishing ports of La Línea de la Concepción (Cádiz), Estepona (Málaga), Fuengirola (Málaga) and Caleta de Vélez (Málaga) (Fig. 1), which harbour the main artisanal fleet that operates with dredges and present the greatest sales for these species along the northern Alboran Sea. Soft bottoms here are composed of terrigenous sediments with a dominance of fine and medium sands, with mud contents ranging between 2–80% depending on the influence of the main river mouths (e.g. Guadiaro, Guadalmansa, Fuengirola, Gualdalhorce, Vélez, Güí and Torróx rivers), and a bioclastic (e.g. empty shells) content that can reach high values in some localities such as in Fuengirola (Sanz et al. 2007; Urra et al. 2011).

Mechanical dredges are the only fishing gear that is allowed in local clam fisheries of the northern Alboran Sea. The artisanal character of this fishery makes these dredges to display some minor different gear characteristics among commercial vessels. During fishing, the stern or "gavilán" anchor is cast and each vessel typically uses three to six sets of dredges simultaneously, which are hauled at low speed (<10 m min^{-1}) by a motorized winch for 15-30 minutes, depending on the target species. Each fishing operation takes about 30 min, and it is repeated making concentric lines around the anchor until a circumference is completed (Fig. 1).

Science-based fishery management plans established by regional government authorities for the appropriate exploitation, conservation and management of marine resources mention, among other issues, that a minimum mesh size for dredges should be adjusted so as to minimize the harvest of undersized individuals. This would allow targeted individuals below the minimum conservation reference size (MCRS hereafter) to reach a size at which they can reproduce at least once before capture. In this line, the MCRS established for the main target clams caught along the northern Alboran Sea are 60 mm (shell length, SL) for *C. chione*, 45 mm (shell height) for *A. tuberculata*, and 25 mm (SL) for *D. trunculus* and *C. gallina* (https://www.juntadeandalucia.es/boja/2003/65/d7.pdf). Nevertheless, the discarding of by-catch by fishing vessels, including individuals of these clams below MCRS, is a common practice in bivalve fisheries as they are incidentally caught by dredges.

Sample collection

Discard samples have been collected from the catches obtained with nine commercial vessels operating with dredges along the northern Alboran Sea (Fig. 1). Clam dredges are comprised of a metallic frame, a toothed lower bar and a mesh bag or a rectangular metallic grid box to retain the catch. Despite the similar design of mechanical dredges, some technical specifications vary according to the target species. This fleet usually operates 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 in the case of wedge clam and striped venus clam fisheries, and/or (ii) with dredges having a net bag (mesh size: 30-40 mm) and a lower number (~20) of longer iron teeth (24 cm) that are set further apart in the case of smooth clam fishery. A total of 278 random discard samples (95 samples for wedge clam fisheries; 106 samples for striped venus clam fisheries; 77 samples for smooth clam fisheries) of ca. 5 kg were collected in 65 fishing trips from March 2013 to March 2014 (based on fishermen availability: 83 samples in spring; 71 samples in summer; 57 samples in autumn; 67 samples in winter). A minimum area (in this case volume) assessment indicated that 5 kg samples were the smallest volume which adequately represented discard composition. Discard samples were stored at -20°C until further processing. Once defrosted, every specimen from each sample was separated, identified to species level (when possible) and quantified (abundance and biomass [±0.1 g wet weight]). Additionally, data regarding the composition and weight of inorganic material (e.g. bioclasts, pebbles) and plant remains (e.g. seagrass, macroalgae, remains of transported terrestrial plants) were also recorded.

Data analysis

Catch abundance and biomass data were standardized to 15 min fishing operations. The abundance, weight, dominance index (percentage of individuals/biomass of a species from the total catch) and frequency index values (percentage of samples in which a species is present) (Glémarec 1964) were calculated for every discarded species. Comparisons between number of species, abundance and biomass of discards per target species and seasons were performed by means of one-factor non-parametric analysis of variance (Kruskal-Wallis) using the SPSS statistical software.

Additionally, the comparison of the number of discarded species was carried out with rarefaction curves, which represent a common method among sample-based datasets that differ in the total number of sampling units (e.g. Jurkiewicz-Karnkowska 2009; Colwell et al. 2011). Sample-based rarefaction and extrapolation curves were developed using the software EstimateS v. 9.1.0 (Colwell, 2013). This approach is recommended in the case of sample heterogeneity (i.e. patchiness) in the data (Gotelli & Colwell, 2001). The samples were randomized without replacement. Estimates were made of rarefied species richness, i.e. the expected species-accumulation curve based on the data of a resampled total observed species (S_{obs}) or sample-based rarefaction (Colwell et al, 2004). The methods that this software uses for extrapolating the species accumulation curve rely on statistical sampling models, using Chao2 for sample-based incidence data (Colwell, 2013).

The similarity between samples was evaluated using both qualitative (presence/absence) and quantitative data (fourth root transformed abundance and biomass data) of species per sample. The similarity index of Bray and Curtis was used as a meaningful and robust measure (Clarke 1993) for obtaining a cluster analysis (UPGMA method) and a MDS ordination. Groups of samples were also compared using an analysis of similarities (ANOSIM; Clarke & Green 1988) in relation to the target species. This analysis is a non-parametric analogue to a multivariate analysis of variance (MANOVA) and compares ranked similarities between and within groups. Finally, a SIMPER (SIMilarity PERcentage) analysis was done in order to know the contribution of the species in the similarity/dissimilarity within and between the same groups of samples. All these multivariate analyses were carried out using the PRIMER software (Clarke & Warwick, 2001).

Regarding biogeographical affinities of discarded species, the geographical sectors considered included Alboran Sea, for all the species found in this study; Mediterranean Sea (ME), excluding those species that do not generally occur east of the Alboran Sea; Ibero-Moroccan Gulf (IM), including the southern coasts of Portugal, Atlantic coasts of Andalusia (southwestern Spain) and Morocco; western Europe (WE), from Portugal to the southern coasts of United Kingdom; northern Europe (NE), from the southern coasts of United Kingdom to Scandinavia; Canary Islands (CN); and western Africa (AF), from Mauritania to tropical western African and also occurring in the Alboran Sea coasts. The presence of the different species in each geographical sector was annotated from specialized literature (see references in Urra et al. 2017a for molluscs) and/or scientific websites such as WORMS (World Register of Marine Species: http://www.marinespecies.org/index.php) and OBIS (Ocean Biogeographic Information Systems: https://obis.org/), and their chorotypes were established. For this purpose, a cluster analysis was performed using raw qualitative data and the Bray-Curtis similarity index, in which species with a similar biogeographical range were grouped.

Results

A total of 129 species (72 families) from 97095 individuals were identified (Table 1). The number of species should be even higher because paguroid decapods and annelids could not be identified to species level. The phylum Mollusca was the most diverse among discards of the three clam fisheries (Fig. 2A), and was represented by four classes and 72 species (spp.), followed by Arthropoda (i.e. Crustacea: 20 spp.), Chordata (i.e. fishes: 20 spp.) and Echinodermata (12 spp.), whereas poorly represented phyla included Cnidaria (3 spp.), Nemertea and Sipunculida (1 spp., respectively). Mollusca (67.5%) and Crustacea (22.0%) dominated in abundance (Fig. 2B), and the former dominated in biomass (94.2%) (Fig. 2C). The best represented families in terms of richness were, within Mollusca, Veneridae (Bivalvia; 10 spp.), Tellinidae, Donacidae, Mactridae (Bivalvia) and Naticidae (Gastropoda; 5 spp., respectively); the family Soleidae (6 spp.) within Chordata; the families Amphiuridae and Astropectinidae (3 spp., respectively) within Echinodermata; and the families Atelecyclidae, Carcinidae and Polybiidae (2 spp., respectively) within Crustacea. In terms of abundance, the most important families were Paguroidea (Superfamily within decapod crustaceans that includes hermit-crabs; 19.2% of the total number of individuals), Veneridae (17.6%), Donacidae (15.2%), Cardidae (Bivalvia; 13.7%), Mactridae (8.4%) and Loveniidae (Echinodermata; 6.2%), whereas the family Cardidae (Bivalvia) overwhelmingly dominated discards regarding biomass (59.7% of the total discarded biomass), followed by Glycymerididae (Bivalvia; 17.6%), Veneridae (10.3%), Mactridae (3.6%) and Loveniidae (2%).

The mean total catch (commercial fraction+discards) was 3722.5±191.6 g haul^{-1} (Mean±SE) for the wedge clam fishery (ca. 57.6% belonging to the target species [TS] and 42.4% belonging to discards [D]); 10248.6±1046.9 g haul^{-1} for the striped venus clam fishery (ca. 27.2% TS and 72.8% D); and 40253.7±3317.3 g haul^{-1} for the smooth clam fishery (ca. 19.6% TS and 80.4% D). From the total collected, four taxa represented >60% of discarded individuals, including Paguroidea (19.2%), and undersized target individuals of *Chamelea gallina* (14.1%), *Donax trunculus* (13.8%) and *Acanthocardia tuberculata* (13.1%) (Table 2, Fig. 3). Regarding weight, two bivalves represented >75% of the total discarded biomass and included *A. tuberculata* and *Glycymeris nummaria* (Table 2, Fig. 2). In relation to frequency of occurrence (% F), ten taxa were very commonly discarded (50-75% F), with *A. tuberculata*, Paguroidea and *C. gallina* as the most frequent ones; another group of ten species were commonly discarded (25-50%) such as the bivalve *Spisula subtruncata*, the sea star *Astropecten irregularis* and the crab *Portumnus latipes*; 13 species were less commonly discarded (12-25%) including the bivalve *Pandora inaequivalvis*, the starfish *Luidia atlantidea* and the crab *Atelecyclus undecimdentatus*; and finally, 99 species were rarely discarded (<12% F) and included mainly molluscs (51 spp.) but also all fishes (20 spp.), many crustaceans (17 spp.) and echinoderms (6 spp.), and less represented taxa such as the nemertean *Cerebratulus marginatus*, as well as the cnidarians *Anemonia sulcata* and *Veretillum cynomorium* (Table 1). Regarding seasonal dynamics of discards, mean abundance (N) and biomass (B) were significantly higher in winter (N: 1184.3±168.1 ind. sample^{-1}; B: 17415.4±2822.1 g sample^{-1}) due to the high values reached by some dominant taxa such as *A. tuberculata*, Paguroidea and the echinoid *Echinocardium* cf. *mediterraneum,* among others, and minimum in spring (N: 737.8±90.4 ind. sample^{-1}) and summer (B: 5513.9±943.5 g sample^{-1}), respectively (Kruskal-Wallis: N- χ^2= 9.7; B- χ^2= 10.2; p< 0.05, respectively). Regarding discarded species richness (S), mean values were similar throughout the year and ranged between 13 and 15 spp sample^{-1} (Kruskal-Wallis: S- p< 0.05).

Multivariate analysis showed three groups of samples corresponding to discards of wedge clam (1.5±0.1 m, mean depth of fishing operations ± SE; minimum depth: 0.5 m, maximum depth: 2.7 m), striped venus clam (4.1±0.1 m depth; min: 2.3 m, max: 6.1 m) and smooth clam fisheries (9.5±0.4 m depth; min: 5.5 m, max: 21.4 m) (Fig. 4). Differences in discards were, in all cases, significant according to the ANOSIM procedure regarding the target species (one-way ANOSIM: Abundance- R_{ANOSIM}= 0.75, p< 0.001; Biomass- R_{ANOSIM}= 0.77, p< 0.001), being more acute between discards of wedge clam and smooth clam fisheries due to the higher abundance and biomass values reached by *D. trunculus*, *P. latipes*, pagurids, *Macomangulus tenuis* and *Liocarcinus vernalis* in discards of wedge clam fisheries, and by *Acanthocardia acuelata*, *A. tuberculata*, *G. nummaria*, *C. chione* and *A. irregularis* in discards of smooth clam fisheries, among others (SIMPER: 89% average dissimilarity). Differences between discards of striped venus clam and smooth clam fisheries (SIMPER: 73% average dissimilarity) were related to the higher abundance and biomass of *C. gallina*, *A. tuberculata*, *Mactra stultorum* (bivalve), *S. subtruncata* and pagurids in discards of striped venus clam fisheries, and of *G. nummaria*, *C. chione*, *A. aculeata* and *A. irregularis* in discards of smooth clam fisheries. Finally, differences between discards of wedge clam and striped venus clam fisheries (SIMPER: 67% average dissimilarity) were related to the higher abundance and biomass of *D. trunculus*, *P. latipes*, pagurids, *M. tenuis* and *Liocarcinus vernalis* in discards of wedge clam fisheries, and of *A. tuberculata*, *C. gallina*, *S. subtruncata*, *M. stultorum* and *Tritia reticulata* in discards of striped venus clam fisheries.

Samples based on fourth root transformed abundance data displayed an ordination according to a depth gradient from shallower (on the right side of the graph and corresponding to samples from wedge clam fisheries) to deeper stations (on the left side of the graph and corresponding to samples from smooth clam fisheries) (Fig. 5). Most species displayed a broad bathymetric range and were widespread in the area, with higher abundance values at their optimal depth (e.g. *C. chione*, *A. tuberculata*, *A. irregularis*, *Ophiura ophiura*; Fig. 5B-E), whereas a few species showed more restricted distributions (e.g. *D. trunculus*, *P. latipes*; Fig. 5F, G).

The mean number of discarded species was significantly higher in discards of the striped venus clam fisheries (17±1 spp. haul^{-1}) (Kruskal-Wallis: χ^2= 86.79; p< 0.05), followed by wedge clam fisheries (14±1 spp. haul^{-1}) (Fig. 6A). Similar results were obtained for the mean number of discarded individuals, with striped venus clam fisheries displaying the highest values (1160±131 ind. haul^{-1}) (Kruskal-Wallis: χ^2= 13.07; p< 0.05) (Fig. 6B). Finally, the mean amount of discarded biomass was overwhelmingly higher for smooth clam fisheries (22932±1973 g haul^{-1}), with significant differences with respect to the other fisheries (Kruskal-Wallis: χ^2= 13.07; p< 0.05) (Fig. 6C). Rarefaction curves showed that the number of discarded species at any plotted sample size (beyond very small samples) is greater for striped venus clam and wedge clam fisheries than for smooth clam fisheries (Fig. 7). When the sample size is rarefied down to 77 samples to match the size of the smooth clam sampling, the order of the three curves is maintained, with an interpolated species richness value of 81 and 80 species for the striped venus clam and the wedge clam, respectively, considerably more than for the smooth clam, with 70 species. On the other hand, none of the three curves showed an asymptote, with that of the smooth clam displaying a greater slope, which suggests a higher species richness to be detected in further sampling. The results for extrapolating the species accumulation curve from the three reference samples (extrapolation curves up to a size of 150 samples) showed that the total number of discarded species is similar for all of them, with overlapping confidence intervals suggesting non-significant differences for this sample size.

Discards were mainly composed of a group of species (73.2% of the total) displaying a wide distributional range in both the Atlantic and the Mediterranean (e.g. *Ocenebra erinaceus*, *Carcinus maenas*, *O. ophiura*), and in some cases extending southwards to western Africa (e.g. *Sepia orbignyana*, *Ophisurus serpens*, *Mactra glauca*), that cluster together with a similarity above 75% (Fig. 8). Discards were also composed by strictly Mediterranean species (9 spp.) that are generally not found in the Atlantic coasts (e.g. *E.* cf. *mediterraneum*, *Astropecten jonstoni*, *Tritia mutabilis, Macropodia longirostris*), another group of species (8 spp.) that are found in the Mediterranean and in the Ibero-Moroccan area (e.g. *Chamelea gallina*, *Euspira macilenta*, *Turritella turbona*), or even southwards in the north-western African coasts and the Canary Islands (7 spp.; e.g. *Astropecten aranciacus*, *Peronaea planata*). A small group of eight species cluster together with a distribution currently restricted to the Ibero-Moroccan area and north-western Africa (e.g. *Sinum bifasciatum*, *Luidia atlantidea*) (Fig. 9); and finally, only nine species are reported in the Mediterranean but not in most of the Atlantic (e.g. *Tritia mutabilis*, *E.* cf. *mediterraneum*) (Fig. 7).

Discussion

Discard analysis has drawn much attention in the recent years as it has been acknowledged as an important aspect for fisheries management, especially after the establishment of the ecosystem approach to fisheries (García et al. 2003; Pikitch et al. 2004) and the implementation of diverse European directives and regulations (e.g. Commission Regulation (EC) No 1639/2001, Regulation (EU) No 1380/2013). Moreover, the assessment of bycatch/discard issues is critical for assessing the sustainability of any fishery. Despite the progress observed in this field (Tsagarakis et al. 2013), information regarding discards is still very scarce for some artisanal fisheries, such as those using mechanical dredges and targeting bivalves performed in the western Mediterranean. In order to solve this, recent research projects focused on increasing the knowledge on clam fisheries operating in the northern Albrorn Sea have allowed characterizing the discards generated by this artisanal fleet. Regarding this, discards of these clam fisheries have shown a high biodiversity, with a higher number of species in comparison to discards of fisheries targeting the same species in other parts of southern Europe (Vaccarella et al. 1998; Morello et al. 2005). This is the result of the high biodiversity of the faunal communities associated with shallow sedimentary habitats of the Alboran Sea (García Raso et al. 2010; Rueda et al. accepted).

The quantification of discards using mechanical dredges revealed significant differences in the composition of the bycatch collected by the two dredges. This would indicate that the faunal composition of soft bottoms varied gradually with depth, with a more acute change around 5 m depth probably due to the lower influence of wave action. Most species occurred over broad depth ranges, overlapping in their vertical distribution patterns; however, most of them reached their highest abundance values over more restricted depth ranges (e.g. *C. chione*, *O. ophiura*). A combination of depth related environmental factors such as granulometric characteristics of sediments, wave action and food supply, as well as the different adaptive responses of taxa to the environment, are key factors determining the distribution of species that have already been cited by different authors (Morin et al. 1985; Brown & McLachlan 1990; Koulouri et al. 2006; Urra et al. 2011). The dominant species observed in discards mainly corresponded to components of two biocoenoses: (1) one found on fine surface-sands exposed to wave action in bottoms down to 5 m depth; and (2) another one found on well-sorted fine sands in bottoms where the waves no longer have a direct effect (Pérès & Picard 1964; Templado et al. 2012). These faunal communities, widely studied throughout the Mediterranean littoral areas (e.g. Koulouri et al. 2006; Labrune et al. 2008; Urra et al. 2011), has a great economic importance as it harbours populations of commercial species (Urra et al. 2018).

The abundance and biomass of discards displayed a significant seasonal trend with maximum values in winter. This temporal trend is similar to that observed for shallow fine sands benthic assemblages (e.g. molluscs) in close areas of southern Spain (Urra et al. 2013) and other areas of north-western Spain (Gestoso et al. 2007; Moreira et al. 2010). This trend would be related to abiotic factors such as higher fluctuations of environmental conditions in cold months, as well as to biotic factors including population dynamics of the dominant species, with some of them showing a marked seasonality that could be related to their biology and ecology (e.g. reproductive or feeding strategies). In this line, different dominant scavengers (e.g. Paguridae decapods) and detritivores (e.g. echinoderms such as *E.* cf. *mediterraneum*) could be benefited by the higher amount of organic particles coming from close rivers during the rainy season (September-February), as previously observed for other bivalve species (Urra et al. 2013). For other species, such as the dominant decapod crustacean *P. latipes*, the higher abundances in winter coincide with a period of high feeding activity and the spawning season (Chartosia et al. 2010). This could be related to migratory movements to shallow areas for feeding or spawning, benefiting from a higher presence of juveniles due to the recruitments occurred during the summer season for a large number of species. This would be the case of the commercial wedge clam, for which *P. latipes* has been reported to be an important predator (Salas et al. 2001). The dominant thick-shelled rough cockle *A. tuberculata* reached very high biomass values throughout the year and especially in winter, probably linked to continuous spawning and recruitment as observed for this species close to the study area by Tirado et al. (2017). These authors reported a reproductive cycle for *A. tuberculata* with an extended sexual activity from January to July, during which successive spawning events were observed, and with small-size individuals being recruited into the population from June to December. Moreover, this species is only collected those years that it is requested by the Spanish canning industry, so it represents a benthic resource that accumulates a high biomass throughout the months.

The faunal composition documented here is similar to the ones observed in discards of clam fisheries in other Mediterranean and close-by areas, with molluscs as the best represented and more abundant faunal group (Vaccarella et al. 1998; Morello et al. 2005; Peharda et al. 2010; Anjos et al. 2018). The ecological importance of molluscs lies in their contribution to the process of transporting nutrients and energy between adjacent species and ecosystems, representing an important food source for higher trophic levels (e.g. Edgar & Shaw 1995; Ruitton et al. 2000; Pasquaud et al. 2010). This type of artisanal fishery is carried out in certain sedimentary habitats whose differences (e.g. grain size, % of organic matter) determine the composition and the structure of the associated faunal communities, which was reflected in the different number of species, individuals and biomass collected in the three clam fisheries. The majority of discards represented relatively few families, likely a consequence of dominance by only a few species (Malaquias et al. 2006). The discard composition was dominated by the presence of undersized target individuals and by benthic species with dimensions and morphological features that prevented their passage through the mesh bag, such as larger bivalve species, hermit crabs and heart urchins. In this line, discards were dominated by a dozen taxa including Paguroidea among crustaceans, the bivalves *C. gallina*, *D. trunculus*, *A. tuberculata*, *C. chione*, *G. nummaria* and *M. stultorum*, and the echinoid *E.* cf. *mediterraneum*, which is in line with previous studies on soft bottom benthic communities of the area (Urra et al. 2011, 2018). Nevertheless, there are certain differences regarding discard composition of the northern Alboran Sea in comparison to other areas, which would be linked to the singular hydrological and biogeographical characteristics of this basin (Rueda et al. accepted).

Discard analysis represents a highly operational way to monitor benthic biodiversity components. Although it does not correspond to a conventional scientific sampling method, fishermen (in this case shell fishermen) usually carry out commercial hauls almost every day throughout the year with similar fishing gears. In ecology, the number of species counted in a biodiversity study is a key metric but is usually a biased underestimate of total species richness because many rare or small species are not detected. Despite this, it becomes a way to get systematic faunal samples for the overall characterization of shallow communities inhabiting fishing grounds (Vaccarella et al. 1998; Monteiro et al. 2001; Morello et al. 2005; Malaquias et al. 2006), especially considering native and exotic range-expanding species. In this line, the heterogeneity of the composition and structure of faunal communities in these sedimentary environments, especially evident in hotspot areas such as the Alboran Sea, imposes a substantial sampling regime if a comprehensive inventory is required, which can benefit from this continuous fishing effort. Moreover, fishers' knowledge of target species, the state of resources and communities as a result of a lifetime of experience in coastal environments and inter-generational communication, is an important source of information that can provide additional data to scientists for those challenges dealing with ecosystems, because scientist and local fishermen may share similar constrains and goals. On the other hand, it would be of interest to develop studies to identify those species that are most affected by mechanical dredge trawling and that can disturb the structure of the faunal community (Gaspar et al. 2003; Urra et al. 2019), in combination with multivariate studies based on ecological indicators (e.g. species richness, diversity, evenness) as a proxy for the long term marine ecosystem health status assessment (Jennings et al. 2001). Regarding this, an accurate data collection program for obtaining time series on the composition of discards is essential to detect patterns of change of faunal communities affected by dredge trawling and its potential impact on ecosystem functioning.

The number of invertebrates and other species of low or no commercial value that are discarded is gradually becoming known for European waters (Monteiro et al. 2001; Erzini et al. 2002; Malaquias et al. 2006). In this line, studies on discards of artisanal fisheries are needed as some European coastal areas harbour a high species richness and diversity, which has important implications in terms of conservation, management and sustainable use of living resources (Urra et al. 2018). This would be the case of the northern Alboran Sea, as this area is located in the Atlantic-Mediterranean transition, where upwellings, downwellings and the mixture of water masses are enhanced by the geomorphology of the Strait of Gibraltar and the Alboran basin itself, which conditions the hydrology of the area and in turn determine the existence of a greater or lesser richness in nutrients, plankton and the presence or not of species or populations of both seas (Delgado 1990; Sarhan et al. 2000; García Raso et al. 2010; Rueda et al. 2010, accepted). In the case presented here, it is noteworthy to mention that the dredge used for the smooth clam has a higher mesh size and thus the number of discarded species is lower, so the potential impact caused by the dredge is balanced against other fisheries carried out on bottoms harbouring less diverse communities but where more species are discarded due to the lower mesh size of the dredge. Moreover, target individuals below size at first sexual maturity for the three commercial bivalve species analyzed here were not retained by the mechanical dredge, which represents a key aspect of natural resource exploitation.

Regarding faunal richness, none of the species found in the analyzed samples are included in the National Catalogue of Threatened Species (Law 42/2007: https://www.boe.es/buscar/pdf/2007/BOE-A-2007-21490-consolidado.pdf), nor in the European Directive 92/43/EEC that ensures biodiversity through the conservation of natural habitats and of wild fauna and flora in the European territory, or the Protocol concerning specially protected areas and biological diversity in the Mediterranean (Barcelona Convention). In relation to the impact caused by fishing gears, a topic that is gaining attention worldwide, especially in those fisheries using gears that can cause acute damages on the seafloor components (Jennings & Kaiser 1998; Lucchetti & Salas 2012), it is worth noting the low proportion of damage that this type of fishery cause to benthic and demersal species in the northern Alboran Sea (Urra et al. 2017b, 2019). The absence of apparent damage promotes the potential survival of discarded individuals once released to the sea (Kaiser & Spencer 1995), being higher if they are released in a short time and on similar original habitats (Anjos et al. 2018), as occur in the clam fisheries analyzed here. Nevertheless, long-term mortality of discards is likely to occur due to sub-lethal damage, internal injuries and physiological stress (Kaiser & Spencer, 1995; Bergmann & Moore, 2001; Jenkins et al. 2001), and post-trawling mortality of discarded organisms may have been underestimated in the past. Despite this, soft bottom benthic communities inhabiting shallow and dynamic environments 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.

The biogeographical singularity of the fauna existing in the transitional zone between the Atlantic and the Mediterranean, with the bulk of species displaying a wide distributional range in the Atlantic, strictly Mediterranean species and Mediterranean species that also occur in the Ibero-Moroccan Gulf, has previously been documented for faunal communities inhabiting different habitats at different depths in the Alboran basin (e.g. for molluscs: Rueda et al. 2009; Marina et al. 2012; Urra et al. 2017a; e.g. for sponges: Sitjà & Maldonado 2014). For instance, Urra et al (2017a) observed that dominant species in molluscan assemblages inhabiting unvegetated habitats (soft bottoms, rocky outcrops) in the north-western Alboran Sea showed wide distributional ranges, being present in four or five geographical sectors from northern Europe to north-western African coasts. Besides, these authors highlighted the presence of at least 23 subtropical molluscan species, with some of them displaying their only European and/or Mediterranean populations (e.g. *Modiolus lulat*). In this context, areas located at “biogeographical crossroads” usually support high species richness and beta diversity, and should be considered a conservation priority (Spector 2002), as it is the case of the Alboran Sea, where some marine protected areas have been recently declared for the benthic biodiversity conservation (Urra et al. 2015).

The analysis of the composition and structure of discarded fauna in combination with the trawling activity of the artisanal fleet is of interest, as changes in the structure and distribution of faunal communities can lead to an overall systematic depletion in highly stressed areas, with loss of biodiversity and a modification of the size distribution of benthic resources (Jennings et al. 2001; Kaiser et al. 2002; Hiddink et al. 2006). Moreover, the long-term systematization of discard analysis is of importance for the assessment of the impact of fisheries on habitats, benthic communities and their interactions, as part of the fishery management under the ecosystem approach to fisheries perspective (García et al. 2003; Pikitch et al. 2004), 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 information can also serve as baseline for monitoring future changes resulting from the decrease or increase of fishing effort, modifications in dredging gears, as well as to evidence of any other possible factor of variability as global warming.

References

Anjos M, Pereira F, Vasconcelos P et al (2018) Bycatch and discard survival rate in a small-scale bivalve dredge fishery along the Algarve coast (southern Portugal). Sci Mar 82(S1):75-90

Baro J, García T, Serna Quintero JM (accepted) Description of artisanal fisheries in northern Alboran Sea. In: Báez JC, Vázquez JT, Camiñas JA, Malouli M (eds) Alboran Sea, Ecosystems and Marine Resources. Springer Nature Series, Springer

Baro J, Ramos F, Camiñas JA, Núñez JC (1992) Las pesquerías de bivalvos de la región surmediterránea española. Instituto Español de Oceanografía (Reports), no. 129

Bergmann M, Moore PG (2001) Survival of decapods crustaceans discarded in the *Nephrops* fishery of the Clyde Sea area, Scotland. ICES J Mar Sci 58:163-171

Bianchi CN, Morri C (2000) Marine biodiversity of the MediterraneanSea: situation, problems and prospects for future research. Mar Poll Bull 40(5):367–376

Brown AC, McLachlan A (1990) Ecology of sandy shores. Elsevier Publishers, Amsterdam

Chartosia N, Kitsos MS, Koukouras A (2010) Seasonal diet of *Portumnus latipes* (Pennant, 1777) (Decapoda, portunidae). Crustaceana 83(9):1101-1113

Clarke KR (1993) Non-parametric multivariate analyses of changes in community structure. Aust J Ecol 18:117–143

Clarke KR, Green RH (1988) Statistical design and analysis for a “biological effects” study. Mar Ecol Prog Ser 46:213–226

Clarke KR, Warwick RM (2001) Change in marine communities: an approach to statistical analysis and interpretation, 2nd edn. Plymouth: Plymouth Marine Laboratory

Colwell RK (2013) EstimateS: Statistical estimation of species richness and shared species from samples. Version 9. Persitent URL <purl.oclc.org/estimates>

Colwell RK, Mao CX, Chang J (2004) Interpolating, extrapolating, and comparing incidence-based species accumulation curves. Ecology, 85:2717–2727.

Colwell RK, Chao A, Gotelli NJ et al (2011) Models and estimators linking individual-based and sample-based rarefaction, extrapolation and comparison of assemblages. J Plant Ecol 5:3-21

Currie DR, Parry GD (1996) Effects of scallop dredging on a soft sediment community: a large-scale experimental study. Mar Ecol Prog Ser 134:131-150

Delgado M (1990) Phytoplankton distribution along the Spanish coast of the Alboran Sea. Sci Mar 54(2):169-178

Edgar GJ, Shaw C (1995) The production and trophic ecology of shallow-water fish assemblages in southern Australia III. General relationships between sediments, seagrasses, invertebrates and fishes. J Exp Mar Biol Ecol 194:107-131

Ekman S (1953). Zoogeography of the Sea. Sidgwick and Jackson, London

Ercilla G, Juan C, Hernandez-Molina FJ et al (2016) Significance of bottom currents in deep-sea morphodynamics: an example from the Alboran Sea. Mar Geol 378:157-170

Erzini K, Costa ME, Bentes L, Borges TC (2002) A comparative study of fisheries composition of discards from five fisheries from the Algarve (southern Portugal). Fisheries Manag Ecol 9:31–40

García SM, Zerbi A, Aliaume C, Do Chi T, Lasserre G (2003) The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook. FAO Fisheries Technical Paper. No. 443. Rome

García Raso JE, Gofas S, Salas C, Manjón-Cabeza ME, Urra J, García Muñoz JE (2010) El mar más rico de Europa: Biodiversidad del litoral occidental de Málaga entre Calaburras y Calahonda. Consejería de Medio Ambiente, Junta de Andalucía, Sevilla

Gaspar MB, Leitão F, Santos MN, Chícharo L, Dias MD, Chícharo A, Monteiro CC (2003) A comparison of direct macrofaunal mortality using three types of clam dredges. ICES J Mar Sci 60(4):733-742

Glémarec M (1964) Bionomie benthique de la partie orientale du Golfe du Morbihan. Cah Biol Mar 5:33–96

Hiddink JG, T Hutton, S Jennings, MJ Kaiser (2006) Predicting the effects of area closures and fishing effort restrictions on the production, biomass, and species richness of benthic invertebrate communities. ICES J Mar Sci 63(5):822-830

Hopkins TS (1978) Physical processes in Mediterranean Basins. In: Kjerfve B (ed) Estuarine Transport Processes. University of South Carolina Press, Columbia, pp. 269-310

Jenkins SR, Beukers-Stewart BD, Brand AR 2001. Impact of scallop dredging on benthic megafauna: a comparison of damage levels in captured and non-captured organisms. Mar Ecol Prog Ser 215:297-301

Jennings S, Kaiser MJ (1998) The effects of fishing on marine ecosystems. Adv Mar Biol 34:201-352

Jennings S, Dinmore TA, Duplisea DE, Warr KJ, Lancaster JE (2001) Trawling disturbance can modify benthic production processes. J Anim Ecol 70:459–475

Jones JB (1992) Environmental impact of trawling on the seabed: a review. New Zealand J Mar Fresh Res 26:59-67

Junta de Andalucía (2012) Caracterización de la pesca costera artesanal en Andalucía. Consejería de Agricultura y Pesca, Sevilla

Kaiser MJ, Spencer BE (1995) Survival of bycatch from a beam trawl. Mar Ecol Prog Ser 126:31–38

Kaiser MJ, Edwards DB, Armstrong PJ, Radford K, Lough NEL, Flatt RP, Jones HD (1998) Changes in megafauna benthic communities in different habitats after trawling disturbance. ICES J Mar Sci 55:353-361

Kaiser MJ, JS Collie, SJ Hall, S Jennings, IR Poiner (2002) Modification of marine habitats by trawling activities: prognosis and solutions. Fish Fish 3(2):114-136

Koulouri P, Dounas C, Arvanitidis C, Koutsoubas D, Eleftheriou A (2006) Molluscan diversity along a Mediterranean soft bottom sublittoral ecotone. Sci Mar 70:573-583

Labrune C, Grémare A, Amouroux JM, Sardá R, Gil J, Taboada S (2008) Structure and diversity of shallow softbottom benthic macrofauna in the Gulf of Lions (NW Mediterranean). Helgoland Mar Res 62:201-214

Lacombe H, Tchernia P (1972) Caractères hydrologiques et circulation des eauxen Méditerranée. In: Stanley DJ (ed) The Mediterranean Sea. Dowden, Hutchinson & Ross, Stroudsberg, pp. 26-36

Lanoix F (1974) Projet Alboran. Etude hydrologique et dynamique de la mer d´Alboran. Technical Report nº66. N Atl Treaty Org Brussels

Lucchetti A, Sala A (2012) Impact and performance of Mediterranean fishing gearby side-scan sonar technology. Can J Fish Aquat Sci 69:1806–1816

Malaquias MAE, Bentes L, Erzini K, Borges TC (2006) Molluscan diversity caught by trawling fisheries: a case study in southern Portugal. Fish Manag Ecol 13(1):39-45

Minas HJ, Coste B, Le Corre P, Minas M, Raimbault P (1991) Biological and geochemical signatures associated with the water circulation through the Strait of Gibraltar and in the western Alboran Sea. J Geophys Res 96:8755-8771

Monteiro P, Araújo A, Erzini K, Castro M (2001) Discards of the Algarve (southern Portugal) crustacean trawl fishery. Hydrobiologia 449(1-3):267-277

Morello EB, Froglia C, Atkinson RJA, Moore PG (2005) Hydraulic dredge discards of the clam (*Chamelea gallina*) fishery in the western Adriatic Sea, Italy. Fish Res 76:430-444

Morin JG, Kastendiek JE, Harrington A, Davis N (1985) Organization and patterns of interactions in a subtidal sand community on an exposed coast. Mar Ecol Prog Ser 27:163–185

Parrilla G, Kinder TH (1987) Oceanografía física del mar de Alborán. Boletín Inst Esp Oceanogr 4(1):133-165

Pasquaud S, Pillet M, David V, Sautour B, Elie P (2010) Determination of fish trophic levels in an estuarine system. Estuar Coast Shelf Sci 86:237-246

Peharda M, Ezgeta-Balić D, Vrgoč N, Isajlović I, Bogner D (2010) Description of bivalve community structure in the Croatian part of the Adriatic Sea - hydraulic dredge survey. Acta Adriatica 51(2):141-157

Pérez M, Rodríguez F (2001) Especies de interés pesquero en el litoral de Andalucía. Junta de Andalucía, Consejería de Agricultura y Pesca. Sevilla

Pérès JM, Picard J (1964) Nouveau manuel de bionomie benthique de la Mer Mediterranée. Recl Trav Sta Mar d'Endoume 31:5-137

Pikitch EK, Santora C, Babcock EA et al (2004). Ecosystem-Based Fishery Management. Science 305:346-347

Rueda JL, Gofas S, Aguilar R et al (accepted) Chapter 10: Benthic fauna of littoral and deep-sea habitats of the Alboran Sea: A hotspot of biodiversity. In: Báez JC, Vázquez JT, Camiñas JA, Malouli M (eds) Alboran Sea, Ecosystems and Marine Resources. Springer Nature Series, Springer

Rueda JL, Urra J, Marina P, Mateo-Ramirez Á, Reina-Hervás JA. 2010. Especies africanas en las costas de Andalucía. Quercus 293:24-31

Ruitton S, Francour P, Boudouresque CF (2000) Relationships between algae, benthic herbivores invertebrates and fishes in rocky sublittoral communities of a temperate sea (Mediterranean). Estuar Coast Shelf Sci 50:217-230

Salas C, Tirado C, Manjón-Cabeza ME (2001) Sublethal foot-predation on Donacidae (Mollusca, Bivalvia). J Sea Res 46:43-56.

Sanz JL, Tello O, Hermida N, Fernández-Salas LM, Pastor E (2007) Hoja MC 056, Vélez-Málaga. Hoja MC057, Málaga (serie A). Serie cartográfica. Estudio de la Plataforma Continental Española. Instituto Español de Oceanografía

Sarhan T, García Lafuente J, Vargas JM, Plaza F (2000) Upwelling mechanisms in the northwestern Alboran Sea. J Mar Systems 23:317-331

Spector S (2002) Biogeographic crossroads as priority areas for biodiversity conservation. Conserv Biol 16(6):1480–1487

Templado J, Ballesteros E, Galparsoro I, Borja A, Serrano A, Marín L, Brito A (2012) Inventario español de hábitats y especies marinos. Ministerio de Agricultura, Alimentación y Medio Ambiente, Madrid.

Templado J (2011) La diversidad marina en España. In: Viejo JL (ed) Biodiversidad: aproximación a la diversidad botánica y zoológica en España. Mem R Soc Espa Hist Nat, Segunda época, Tomo IX, Madrid, pp 343–362

Tirado C, Marina P, Urra J et al (2017) Reproduction and population structure of *Acanthocardia tuberculata* (Linnaeus, 1758) (Bivalvia: Cardiidae) in southern Spain: implications for stock management. J Shellfish Res 36:61-68

Tsagarakis K, Palialexis A, Vassilopoulou V (2013) Mediterranean fishery discards: review of the existing knowledge. ICES J Mar Sci 71(5):1219-1234

Urra J, García T, León E, Gallardo-Roldán H, Lozano M, Rueda JL, Baro J (2019) Effects of mechanized dredging targeting *Chamelea gallina*, striped venus clams, on the associated discards in the northern Alboran Sea (Western Mediterranean Sea). J Mar Biol Ass UK 99(3):575-585

Urra J, Rueda JL, Marina P, Antit M, Salas C (2018) Populations of Commercial Molluscs within a Highly Biodiverse Marine Protected Area of the Northern Alboran Sea (W Mediterranean): Preferential Habitats, Seasonal Dynamics and Importance for Artisanal Fisheries. Thalassas 34(2):349-359

Urra J, Gofas S, Rueda JL, Marina P, Mateo-Ramírez Á, Antit M, Salas C (2017a) Biodiversity and biogeographical patterns of molluscan assemblages in vegetated and unvegetated habitats in the northern Alboran Sea (W Mediterranean Sea). Mar Biodivers 47(1):187-201

Urra J, García T, Gallardo-Roldán H, León E, Lozano M, Baro J, Rueda JL (2017b) Discard analysis and damage assessment in the wedge clam mechanized dredging fisheries of the northern Alboran Sea (W Mediterranean Sea). Fish Res 187:58-67

Urra J, Marina P, Rueda JL et al (2015) New Marine Protected Areas for the benthic biodiversity conservation in the Alboran Sea. In: Díaz del Río V, Bárcenas P, Fernández-Salas LM, López-González N, Palomino D, Rueda JL, Sánchez-Guillamón O, Vázquez JT (eds) Volumen de Comunicaciones presentadas en el VIII Simposio sobre el Margen Ibérico Atlántico. Ediciones Sia Graf, Málaga, pp. 675-678

Urra J, Marina P, Salas C et al (2013) Seasonal dynamics of molluscan assemblages associated with littoral soft bottoms of the NW Alboran Sea (Western Mediterranean Sea). Mar Biol Res 9(7):645-660

Urra J, Gofas S, Rueda JL, Marina P (2011) Molluscan assemblages in littoral soft bottoms of the Alboran Sea (Western Mediterranean Sea). Mar Biol Res 7:27–42

Vaccarella R, De Giosa E, Troplinj B, Paparella P (1998) Exploitation of beds of truncate Donax (*Donax trunculus*) along Adriatic coasts of Albania. Rapp Comm Int Mer Medit 35(2):498-499

Figure Legends

Fig 1. Map of the study area in the northern Alboran Sea (western Mediterranean Sea), showing the location of the artisanal shellfish hauls analyzed (black circles). Inset: diagram of the fishing technique.

Fig 2. Composition of discarded catch of clam fisheries with mechanical dredges in relation to (A) species richness, (B) abundance, and (C) biomass. Percentages calculated as number or weight of species/individuals from the main faunal groups from the total.

Fig 3. Macrobenthic organisms highly abundant in discards of clam fisheries in the northern Alboran Sea: (A) *Liocarcinus vernalis*; (B) *Portumnus latipes*; (C) *Echinocardium* cf. *mediterraneum*; (D) *Donax trunculus*; (E) *Bosemprella incarnata*; (F) *Tritia reticulata*; (G) *Chamelea gallina*; (H) *Dosinia lupinus*; (I) *Donax venustus*; (J) *Spisula subtruncata*; (K) Paguroidea using a shell of *T. reticulata*; (L) *Ophiura ophiura*; (M) *Mactra stultorum*; (N) *Callista chione*; (O) *Acanthocardia tuberculata*; (P) *Acanthocardia aculeata*; (Q) *Calyptraea chinensis*; (R) *Glycymeris nummaria*; (S) *Atelecyclus undecimdentatus*; (T) *Acrocnida brachiata* and (U) *Astropecten irregularis*. Scale bars represent 1 cm.

Fig 4. Cluster based on quantitative (fourth root transformed abundance data) similarities (Bray–Curtis measure) among discard samples of clam fisheries in the northern Alboran Sea. Results were very similar using both presence/absence of species and biomass data.

Fig 5. MDS (A) based on quantitative (fourth root transformed abundance data) similarities (Bray–Curtis measure) among discard samples of clam fisheries in the northern Alboran Sea, with indication of the sampling depth per target species. Spatial distribution of some of the most frequently discarded species and total abundance of specimens collected in each sampling station (B-G).

Fig 6. (A) Species richness (number of species), (B) abundance (number of individuals) and (C) biomass (grams) values for the different faunal groups collected in discards of clam fisheries in the northern Alboran Sea. Mean±standard error. Note that in (C), biomass data for discards of the smooth clam fishery discards presents the axis to the right of the graph.

Fig 7. Sample-based interpolation (rarefaction; solid lines) and extrapolation (broken lines) for reference samples (filled circles) for macrobenthic organisms in discards of clam fisheries in the northern Alboran Sea, with 95% unconditional confidence intervals (shaded areas).

Fig 8. Cluster analysis displaying groups of species that are present in different biogeographical sectors using the Bray-Curtis similarity index. NE, northern Europe; WE, western Europe; IM, Ibero-Moroccan Gulf; ME, Mediterranean Sea; AF, western Africa; CN, Canary Islands.

Fig 9. Subtropical species in discard samples of clam fisheries in the northern Alboran Sea: (A) *Albunea carabus*; (B) *Luidia atlantidea*; (C) *Sinum bifasciatum*; (D) *Cochlis vittata*; (E) *Tectonatica sagraiana*; (F) *Gari pseudoweinkauffi*; (G) *Cymbium olla*; (H) *Mesalia mesal*; (I) *Bivetiella cancellata*. Scale bars represent 1 cm.

Table Legends

Table 1. List of discarded species in shellfish fisheries in the northern Alboran Sea. Species are categorized according to the frequency of occurrence (% F) in discards as very commonly discarded (VCD; 50% <% F <75%), commonly discarded (CD; 25% <% F <50%), less commonly discarded (12% <% F <25%) and rarely discarded (% F <12%).

Table 2. Top-20 dominant discarded taxa in shellfish fisheries in the northern Alboran Sea. %N, proportion of the total discarded abundance; %B, proportion of the total discarded biomass. Species belong to the following taxonomic groups: ^{1}Order Decapoda (Crustacea); ^{2}Class Bivalvia (Mollusca); ^{3}Class Echinoidea (Echinodermata); ^{4}Class Gastropoda (Mollusca); ^{5}Class Ophiuroidea (Echinodermata); ^{6}Class Asteroidea (Echinodermata).